



Staff Report of the
CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY
REGIONAL WATER QUALITY CONTROL BOARD
CENTRAL VALLEY REGION

TOTAL MAXIMUM DAILY LOAD
FOR LOW DISSOLVED OXYGEN IN THE
SAN JOAQUIN RIVER



June 2003

State of California
California Environmental Protection Agency
REGIONAL WATER QUALITY CONTROL BOARD
CENTRAL VALLEY REGION

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Acronyms/Abbreviations

Basin Plan	Water Quality Control Plan for the Central Valley-Sacramento/San Joaquin Basins
BL	Background Loading
BOD	Biological Oxygen Demand
BPTCP	Bay Protection and Toxic Cleanup Plan
CBOD	Carbonaceous Biological Oxygen Demand
CEQA	California Environmental Quality Act
CFR	Code of Federal Regulations
cfs	Cubic Feet Per Second
CVP	U.S. Bureau of Reclamation, Central Valley Project
CVRWQCB	Central Valley Regional Water Quality Control Board
CWA	Clean Water Act
CWC	California Water Code
Delta	Sacramento/San Joaquin Delta
DMC	Delta-Mendota Canal
DO	Dissolved Oxygen
DWR	California Department of Water Resources
DWSC	Stockton Deep Water Ship Channel
LA	Load Allocation
LC	Loading Capacity
mg/L	Milligrams Per Liter
MLLW	Mean Lower Low Water
MOS	Margin of Safety
NEPA	National Environmental Policy Act
NPDES	National Pollutant Discharge Elimination System
Regional Board	Central Valley Regional Water Quality Control Board
RWCF	City of Stockton Regional Wastewater Control Facility
RWQCB	Central Valley Regional Water Quality Control Board
SDIP	South Delta Improvements Project
SJR	San Joaquin River
SJVDP	San Joaquin Valley Drainage Program
TMDL	Total Maximum Daily Load

Acronyms/Abbreviations (continued)

USACOE	United States Army Corps of Engineers
USBR	United States Bureau of Reclamation
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
UVM	Ultrasonic Velocity Meter
WLA	Wasteload Allocation
WQO	Water Quality Objective

EXECUTIVE SUMMARY

Water Body Name:	San Joaquin River in the Stockton Deep Water Ship Channel (DWSC) between the City of Stockton and Disappointment Slough
Project Area:	The portion of the San Joaquin River Watershed that drains downstream of Friant Dam and upstream of Disappointment Slough, excluding portions of the watershed that drain upstream of the dams on the major east side tributary reservoirs.
Pollutants Addressed:	Organic Enrichment, Low Dissolved Oxygen
Extent of Impairment:	14 river miles, 1,461 acres
Beneficial Uses Affected:	Warm freshwater species (striped bass, sturgeon, and shad) migration and spawning (WARM MIGR and WARM SPWN); cold freshwater species (salmon and steelhead) migration. (COLD MIGR); and warm and cold freshwater species habitat (not including anadromous species) (WARM and COLD);
Numeric Target:	Basin Plan numeric objectives: 6 mg/L from 1 September through 30 November and 5 mg/L at all other times
Watershed Characteristics:	Highly managed hydrology with numerous tributary impoundments and extensive diversion of river flows. Substantial water importation from Delta for irrigation and wetland supply. Flows and water quality are significantly influenced by surface and subsurface agricultural drainage.

This TMDL report provides an overview of the TMDL and program of implementation being developed to address the dissolved oxygen (DO) impairment of the Stockton Deep Water Ship Channel (DWSC) between the City of Stockton and Disappointment Slough. The DWSC is a portion of the San Joaquin River (SJR) between the City of Stockton and the San Francisco Bay that has been dredged to allow for the navigation of ocean-going vessels to the Port of Stockton. The impaired reach of the SJR addressed by this TMDL does not meet numeric DO objectives included in Central Valley Regional Water Quality Control Board (CVRWQCB) *Water Quality Control Plan for the Sacramento River Basin and the San Joaquin River Basin, Fourth Edition*, hereafter referred to as the Basin Plan (CVRWQCB, 1998). The numeric targets are the existing numeric DO objectives: 6 mg/L from 1 September through 30 November and 5 mg/L at all other times. No new water quality objectives are proposed at this time.

Numerous studies over the last several years have provided significant data and information on the causes of the DO impairment. From all the studies, three main contributing factors to the problem have been identified:

- Loads of oxygen demanding substances from upstream enter the DWSC where they oxidize and exert an oxygen demand.
- DWSC geometry reduces the assimilative capacity of the DWSC for loads of oxygen demanding substances by reducing the efficiency of natural re-aeration mechanisms and by magnifying the effect of oxygen demanding reactions.
- Reduced flow through the DWSC reduces the assimilative capacity by reducing upstream inputs of oxygen to the DWSC and increasing the residence time for oxygen demanding reactions that further impact DO concentrations.

Although they are contributing factors, DWSC geometry and reduced flows through the DWSC do not contribute loads of oxygen demanding substances. Instead, these factors reduce the capacity of the DWSC to assimilate loads of oxygen demanding substances.

The loading capacity of the DWSC to accept loads of oxygen demanding substances is calculated as a function of flow through the DWSC and water temperature. This loading capacity is expressed as an allowable rate of oxygen demand at the point of lowest DO concentration in the DWSC. The loading capacity available for this TMDL, however, must be reduced to account for the effects of DWSC geometry and reduced DWSC flow.

DWSC geometry and reduced DWSC flow share equal responsibility for the impairment because of the interdependent nature of the three main contributing factors. Similarly, entities responsible for those contributing factors share equal responsibility for mitigation of their impacts. As such, this TMDL divides the total theoretical loading capacity, less a margin of safety, equally among the three main contributing factors. For the portion of the loading capacity attributable to loads of oxygen demanding substances, specific TMDL wasteload and load allocations are proposed for sources based on their linkage to the DO impairment. The two non-load related factors (DWSC geometry and reduced flows through the DWSC), however, are not associated with discharges of a substance and cannot be assigned typical wasteload or load allocations. Instead, this TMDL assumes that mitigation for these factors will be addressed by the responsible entities through means other than TMDL wasteload or load allocations.

The ability to allocate loading capacity to specific sources of oxygen demanding substances is limited by the need for further technical studies, therefore, this TMDL is phased. Further study of linkages between various potential sources of oxygen demanding substances to the low DO impairment is required. Further study is also required of how DWSC geometry and reduced flow impact assimilative capacity. As further information becomes available, the wasteload and load allocations and relative apportioning of loading capacity between the contributing factors may be modified in the next phase of the TMDL.

In 1999, the CVRWQCB provided an opportunity for a Steering Committee watershed stakeholder groups to suggest its own load allocation and implementation plan to Regional Board staff for consideration in the development of the TMDL and program of implementation. A

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report summarizing the Steering Committee recommendations for a TMDL program of implementation was submitted to staff in February 2003 (Ploss, 2003). The Steering Committee chose not to recommend a TMDL load allocation. The Steering Committee proposed a phased approach, which addresses the need for more time to gather additional information on certain sources and linkages to the DO impairment, while at the same time moving forward on making improvements to DO conditions in the DWSC. More information is also needed on performance and cost information for possible mitigation alternatives to bring the DWSC into compliance with the Basin Plan DO objectives.

The proposed Steering Committee plan provided a generally acceptable implementation framework, which has become the basis for the program of implementation being developed for inclusion in the Basin Plan Amendment. This program of implementation will be included along with the TMDL in a Basin Plan amendment that will be proposed for consideration by the CVRWQCB in June 2004.

The program of implementation described in this TMDL provides responsible entities an opportunity to execute the implementation plan they suggested to the CVRWQCB. To the extent that responsible entities do not meet specific implementation milestones, the CVRWQCB and/or the State Water Resources Control Board will have to rely upon their regulatory authority over the various contributing factors to require the necessary mitigation. This report outlines the TMDL approach that would be the basis for such regulatory action.

Load Allocation Summary:

Allocation Type	Description
Margin of Safety	40 percent of the total theoretical loading capacity
Background Loading	Zero
Assumptions	One third of the loading capacity, less the margin of safety, will be addressed by entities responsible for DWSC geometry and one third, less the margin of safety, by those responsible for reduced DWSC flow. These two non-load related factors will be addressed by means other than load or wasteload allocations.
Waste Load Allocations	Thirty percent of the remaining one-third of the loading capacity, less the margin of safety, is allocated to loads of oxygen demanding substances from Stockton RWCF
Load Allocations	Seventy percent of the remaining one-third of the loading capacity, less the margin of safety, is allocated to loads of algae from upstream

1.0 PROBLEM STATEMENT

1.1 Clean Water Act Section 303(d) and TMDL Process

Section 303(d)(1)(A) of the federal Clean Water Act (CWA) requires that “Each State shall identify those waters within its boundaries for which the effluent limitations ... are not stringent enough to implement any water quality standard applicable to such waters.” The CWA also requires states to establish a priority ranking for waters on the Section 303(d) list of impaired waters and to establish a total maximum daily load (TMDL) for those listed waters. Essentially, a TMDL is a planning and management tool intended to identify, quantify, and control the sources of pollution within a given watershed to the extent that water quality objectives are achieved and the beneficial uses of water are fully protected. A TMDL is defined as the sum of the individual wasteload allocations to point sources, load allocations to non-point sources and background loading. Loading from all pollutant sources must not exceed the loading (or assimilative) capacity of a water body, including an appropriate margin of safety. The loading capacity is the amount of pollutant that a water body can receive without violating the applicable water quality objectives.

The specific requirements of a TMDL are described in the United States Code of Federal Regulations (CFR) Title 40, Sections 130.2 and 130.7 (40 CFR § 130.2 and 130.7), and Section 303(d) of the CWA. In California, the authority and responsibility to develop TMDLs rests with the Regional Boards. The U.S. Environmental Protection Agency (USEPA) has federal oversight authority for the CWA Section 303(d) program and may approve or disapprove TMDLs developed by the state. If the USEPA disapproves a TMDL developed by the state, the USEPA is then required to establish a TMDL for the subject water body.

In California, the Porter-Cologne Water Quality Control Act (California Water Code (CWC), Division 7, Water Quality) requires a program of implementation for a TMDL to be included along with the TMDL into the Basin Plan (CWC § 13050(j)(3)). This program of implementation must include a description of actions necessary to achieve Basin Plan water quality objectives, a time schedule for specific actions to be taken, and a description of monitoring to determine attainment of objectives.

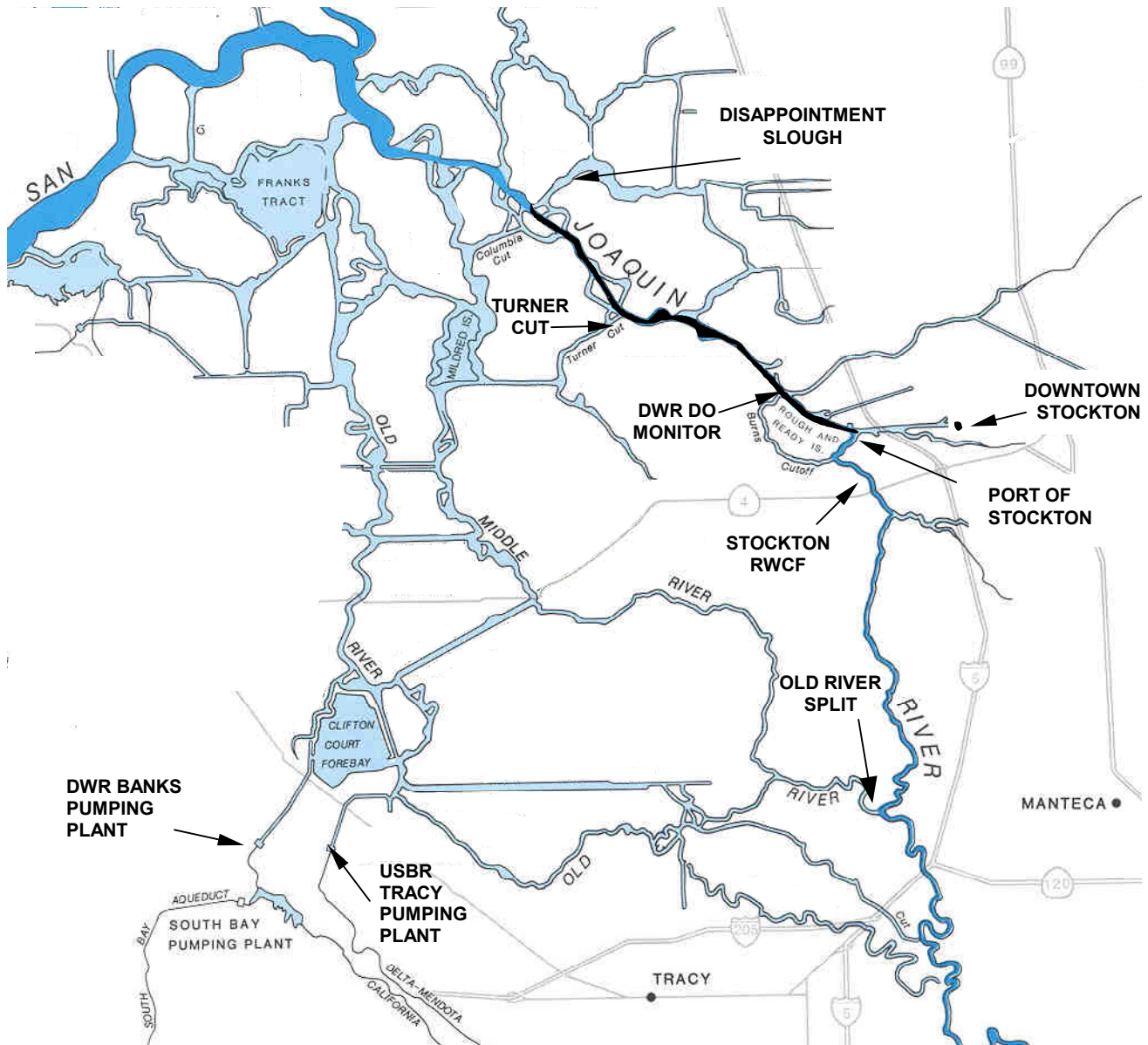
1.2 TMDL Watershed Setting

The dissolved oxygen (DO) impairment is caused, in part, by loads of oxygen demanding substances and other contributing factors that originate in the San Joaquin River (SJR) watershed upstream of the impaired reach. The land uses and hydrology for this larger area must therefore be considered, along with those within the impaired reach, in developing this TMDL and program of implementation.

1.2.1 Dissolved Oxygen Impairment and Source Area

The impaired reach of the SJR addressed by this TMDL does not meet the applicable water quality objectives for DO. The Stockton Deep Water Ship Channel (DWSC) is a portion of the SJR between the City of Stockton and the San Francisco Bay that has been dredged to allow for the navigation of ocean-going vessels to the Port of Stockton. The DO impairment addressed by this TMDL is located in the first 14 miles of the DWSC between the City of Stockton and Disappointment Slough as shown in Figure 1-1.

Figure 1-1: Low Dissolved Oxygen TMDL Vicinity Map

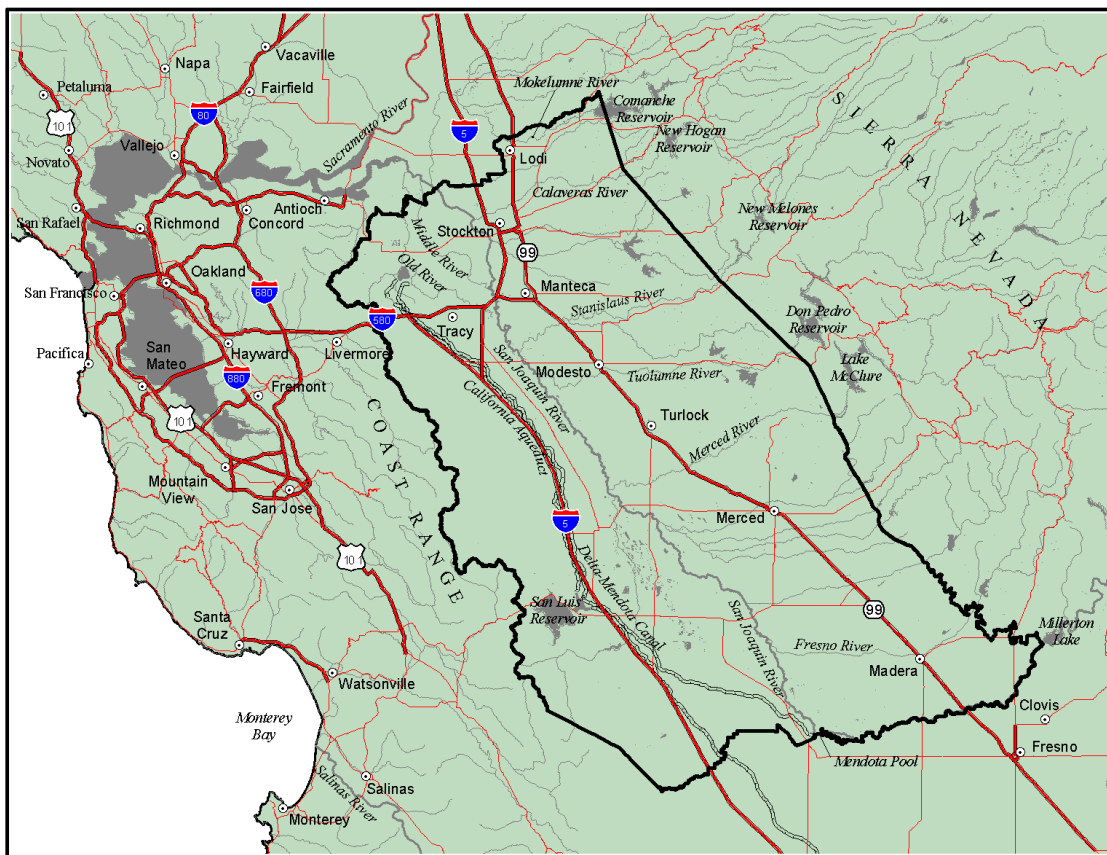


The DO impairment is caused, in part, by loads of oxygen demanding substances and other contributing factors that originate upstream in a portion of the San Joaquin River (SJR) watershed. This DO TMDL source area includes portions of the SJR watershed tributary to the impaired reach of the DWSC downstream of Friant Dam. This source area excludes portions of the watershed that drain upstream of the dams on the major east side tributary reservoirs: New Melones on the Stanislaus River; New Don Pedro on the Tuolumne River; and Lake McClure on the Merced River, nor does it include portions of the SJR watershed in Mariposa, Tuolumne,

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Calaveras, and Amador Counties. There is little potential for agricultural or wetland inputs of oxygen demanding substances or other contributing factors from these areas, except during very high flows when they would likely not contribute to the DO impairment. The reach of the SJR downstream of Vernalis, including the entire length of the DWSC, and a portion of this DO TMDL source area are within the jurisdictional boundaries of the Sacramento-San Joaquin Delta (Delta) as defined in CWC Section 12220. Figure 1-2 below provides a map of the TMDL source area boundary.

Figure 1-2: Dissolved Oxygen TMDL Source Area



In addition to the DO impairment addressed by this TMDL, the SWRCB has included portions of the SJR watershed on the CWA Section 303(d) list for impairments caused by ammonia, diazinon, chlorpyrifos, selenium, unknown toxicity, DDT, mercury, group A pesticides, electrical conductivity and boron. Though this TMDL focuses exclusively on the DO impairment in the DWSC, there will be coordination with these other TMDLs in the watershed.

The Basin Plan amendment for this low DO TMDL and its program of implementation will be proposed to the Regional Board for adoption by June 2004.

1.2.2 Land Use

The San Joaquin Valley has historically been recognized as the leading region for agricultural production in the State of California as well as the nation. Dry conditions make irrigation necessary for nearly all crops grown commercially in the watershed. Surface runoff and subsurface drainage from agricultural activities is either returned to irrigation canals for reuse or is collected in drainage canals and returned to the SJR or a tributary.

In addition to agriculture, the San Joaquin Valley is known for its high natural resource values. It is estimated that the San Joaquin Valley once contained about 1.1 million acres of permanent and seasonal wetlands, with approximately 731 thousand acres occurring within the SJR watershed. Prior to major water developments, the SJR watershed supported a major Chinook Salmon fishery and tens of thousands of salmon probably spawned in its headwaters (SWRCB, 1987), however, steady declines in fish and wildlife habitat have occurred in connection with large-scale agricultural and urban water development. Approximately 85 percent of the historic seasonal and permanent wetlands in the San Joaquin Valley have been drained and/or reclaimed for agricultural purposes (SJVDP, 1990). The San Joaquin Valley, however, remains a critical habitat for fish and wildlife with as many as twenty-four state or federally listed threatened and endangered species (plant and animal) found in the valley.

The SJR is also an important drinking water source for the State of California. SJR flows account for approximately 15 percent of the total flows in the Delta. The Delta provides drinking water for over two thirds of the people in California (more than 20 million people) (SWRCB, 1995). Most of Southern California, a major portion of the San Francisco Bay area, and many Central Valley communities rely on the Delta and its tributaries for their drinking water. The major Sierra Nevada tributaries of the SJR (Stanislaus, Tuolumne, and Merced Rivers) provide drinking water to residents of the San Francisco Bay area and communities in the San Joaquin Valley.

Urban areas within the SJR watershed are expanding and the population of the 13 largest cities in the SJR watershed increased an average of 1.5 percent between 1998 and 1999 (CDF, 1999). Stockton is the largest city in the DO TMDL source area, with a current population of about 250,000. Other urban areas in the DO TMDL source include the cities of Modesto (pop. 200,000), Merced (pop. 62,000), Turlock (pop. 60,000), Ceres (pop. 36,000), Los Banos (pop. 26,000), and Atwater (pop. 23,000).

1.2.3 Hydrology

Precipitation is unevenly distributed throughout the SJR Watershed. About 90 percent of the precipitation falls during the months of November through April. Normal annual precipitation ranges from an average of 8 inches on the valley floor to about seventy inches at the headwaters in the Sierra Nevada. Precipitation at the higher elevations primarily occurs as snow. Potential evaporation on the valley floor is over 50 inches annually (Oppenheimer and Grober, 2002).

The hydrology of the SJR is complex and highly managed through the operation of dams, diversions, and supply conveyances. Water development has fragmented the watershed and greatly altered the natural hydrology of the river. Runoff from the Sierra Nevada and foothills is regulated and stored in a series of reservoirs on the east side of the SJR. Most of the natural

flows from the Upper SJR and its headwaters are diverted at the Friant Dam via the Friant-Kern Canal to irrigate crops outside the SJR Basin. This leaves much of the river dry between Friant Dam and the Mendota Pool, except during periods of wet weather flow and major snow melt. Water is imported to the basin from the southern Delta via the Delta Mendota Canal (DMC) to replace the flows that are diverted out of the basin to the south. Some water in the DMC is delivered directly to the west side of the SJR for agricultural supply, but the majority of DMC water is delivered to the Mendota Pool and distributed from there via irrigation canals to the west side. Water is also released to the SJR from Mendota Pool to meet the needs of various agricultural users between the Mendota Pool and the Sack Dam. Most or all of the remaining flow in the river is diverted at Sack Dam. As a result, the SJR downstream of Sack Dam and upstream of Bear Creek frequently has little or no flow except during flood flows. During non flood-flow periods, this reach of the SJR flows intermittently and is composed of groundwater accretions and agricultural return flows.

The SJR downstream of Bear Creek once again becomes a permanent stream that flows all year. Except during high rainfall and flood flows during wet years, the flow in the reach of the SJR downstream of Bear Creek and upstream of the Merced River confluence is dominated by agricultural and wetland return flows, groundwater accretions, and inflow from Mud Slough and Salt Slough. Mud Slough and Salt Slough drain the 370,000-acre Grassland Watershed. These sloughs contain a mix of agricultural return flows, runoff from managed wetlands, rainfall runoff, and flood flows. Mud Slough discharges to the SJR approximately two miles upstream of the confluence of the SJR and the Merced River. Salt Slough flows into the SJR approximately six miles upstream of the Mud Slough confluence.

The major tributaries to the SJR upstream of the Airport Way Bridge near Vernalis (the legal boundary of the Delta) are on the east side of the San Joaquin Valley, with drainage basins in the Sierra Nevada Mountains. These major east side tributaries are the Stanislaus, Tuolumne, and Merced Rivers. The Cosumnes, Mokelumne, and Calaveras Rivers and French Camp Slough flow into the SJR downstream of the Airport Way Bridge near Vernalis. Several smaller, ephemeral streams flow into the SJR from the west side of the valley. These streams include Hospital, Ingram, Del Puerto, Orestimba, Panoche, and Los Banos Creeks. All have drainage basins in the Coast Range, flow intermittently, and contribute sparsely to water supplies. During the irrigation season, surface and subsurface agricultural return flows contribute greatly to these creeks and sloughs.

Once the SJR reaches Vernalis, tidal stages in the Delta begin to affect its flow. The SJR flow through the DWSC is strongly affected by tidal stage, which can range from about 0.25 feet below mean sea level to about 4.25 feet above mean sea level. The ebb flows are relatively steady for several hours at about 2,500 cfs plus the flow from the SJR. As the flood tide raises water levels, the ebb flows gradually decreases, and after a short period of stagnation, flow reverses. This flood tide flow averages about 2,500 cfs minus SJR river flows. This tidal cycle repeats itself every 24.8 hours and varies in intensity throughout the 28-day lunar cycle (Brown and Renehan, 2001).

1.3 Nature of Dissolved Oxygen Impairment

Over the last 20 years the California Department of Water Resources (DWR) has collected DO data in the DWSC at its Rough & Ready Island continuous monitoring station and as part of semi-regular cruises with the *San Carlos* floating laboratory. These data provide excellent characterization of the spatial extent and temporal variability of the DO impairment.

1.3.1 Available Data

Since 1983 DWR has operated a continuous reading DO monitor and data logger in the DWSC at the northern end of Rough and Ready Island as indicated in Figure 1-1. The DO monitoring station consists of a continuous reading DO probe installed in a flow-through cell. This cell has an intake located about three feet below the surface inside a perforated pipe that extends seventeen feet below the surface. This configuration was determined to produce a somewhat depth-integrated measurement. Understanding this configuration is important in interpreting the data, because vertical DO gradients that may exist at various times at this location can cause the vertically integrated measurement to be different from actual values at the surface or bottom. The probe is calibrated weekly using a grab sample analyzed by the Winkler method. The meter reads DO once every second; data is reviewed by DWR staff and is reported as one-hour averages in the DWR Interagency Ecological Program database (Stringfellow, 2001).

Each year since 1983 DWR has also performed boat cruises in the DWSC sampling DO at 14 locations between Disappointment Slough and the City of Stockton. The boat cruises occur roughly twice a month typically between August and November, but sometimes as early as July and as late as December. Two sets of DO and temperature measurement are taken at each location, one set at three feet below the surface and another near the bottom. The measurements are taken during ebb slack tide using continuous monitoring instruments and Winkler titration. When the stations are sampled, all 14 locations are sampled within about four hours beginning at about 9:00 AM at the downstream station and progressing upstream to the most upstream station (Ralston, personal communication, 2001).

Other data relevant to the DO impairment have been collected by the City of Stockton and numerous other agencies, researchers and interest groups. Much of this data and associated analysis is summarized or referenced in *Synthesis and Discussion of Findings on the Causes and Factors Influencing Low DO in the San Joaquin River Deep Water Ship Channel near Stockton, CA: Including 2002 Data* prepared by G. Fred Lee and Anne Jones-Lee in March 2003 (Lee and Jones-Lee, 2003), hereafter referred to as the Synthesis Report.

1.3.2 Spatial Extent of Impairment

An extensive presentation and analysis of DO data collected by the DWR boat cruises is contained in the Synthesis Report, where the following conclusions were made regarding the spatial extent of DO concentrations in the DWSC:

- DO concentrations less than the Basin Plan objectives occur off Rough & Ready Island and may extend down to Turner Cut.
- The point of greatest DO depletion tends to be shifted downstream toward Turner Cut with increased flow rates through the DWSC.

- DO concentrations below the Basin Plan objectives do not occur downstream of Disappointment Slough, and rarely occur downstream of Turner Cut.
- On the average DO concentrations measured near the bottom were 0.3 mg/L lower than near the surface (Lee and Jones-Lee, 2003, pgs. 23 – 24).

DO concentration profiles in the DWSC appear to follow a sag profile similar to one predicted by a simple Streeter-Phelps model. It appeared that the location of the low point in the sag profile moved downstream and lessened in severity as flow increased. The results of this analysis also suggested that the severity the low DO concentration was strongly influenced by BOD concentrations entering the DWSC and temperature (Foe, *et al.*, 2002, pgs. 9 – 15).

1.3.3 Temporal Variability

Except for sporadic gaps, the DWR DO monitoring station at Rough & Ready Island provides year-round hourly DO data beginning in May 1983. This data has been compiled in Table 1-1 to demonstrate the relative frequency of low DO conditions experienced in each month of the year.

For each month of the year in Table 1-1, the upper number presented is the percentage of hourly DO measurements below 5.0 mg/L recorded that month. If a cell is blank, there were no DO measurements below 5.0 mg/L that month. If a cell contains “n/a”, no data was recorded at all for that month. The lower italicized number presented for each month is the minimum DO concentration measured that month. The average rate (weighted to account for months with partial data sets) for the 19-year period is shown in the bottom row. The average monthly excursion rate ranged, on the average, from 4 to 37 percent. The worst months of the year for low DO tend to be June through October with the excursion rate ranging from 23 to 37 percent. This suggests that there is a seasonal influence on the frequency of occurrence of low DO in the DWSC. It can also be observed that as the excursion rate increases in a month, the severity of the DO impairment also increased (Foe, *et al.*, 2002, pg. 6). As discussed in the next section, the DO water quality objective for the impaired portion of the SJR is 6.0 mg/L between 1 September and 30 November and 5.0 mg/L all other months of the year. For the purpose of comparing the relative severity of DO concentrations in different months, Table 1-1 makes comparisons to a constant 5.0 mg/L concentration. The excursion rate above the 6.0 mg/L portion of the DO water quality objective would be higher than those shown in the months of September through November.

The DO concentrations in the DWSC as measured at the DWR DO monitor between 1983 and 2001 also show diel variation. The variation between peak DO concentrations during daylight hours versus low DO concentrations during nighttime hours averaged about 1 mg/L in the months of June through September. The variation was less in other months of the year, presumably as algal activity is less during those months (Foe, *et al.*, 2002, Appendix C).

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Table 1-1: Temporal Distribution of Low Dissolved Oxygen Impairment

Year		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1983	Excursion rate (%) ¹	n/a	n/a	n/a	n/a								
	Minimum [DO] ²												
1984	:				1	7	84	91	62	2			
	:				4.4	3.9	3.0	2.8	4.0	4.7			
1985	:				6		48	78	15				
	:				4.4		3.3	3.5	4.2				
1986	:	29				5		21	9				
	:	4.4				3.1		4.5	4.8				
1987	:					44	43	3		29		<1	
	:					3.5	3.6	4.6		3.9		4.9	
1988	:	51	52	52			3		10	62			
	:	3.5	3.3	3.8			4.8		4.4	2.3			
1989	:			65	<1		37	2		38	14		
	:			3.7	4.9		4.1	4.8		2.4	4.2		
1990	:			1	5	3	11	<1	<1				
	:			4.8	4.6	4.7	4.5	4.8	4.9				
1991	:		<1	8	37	34	1	5	14	55	99		
	:		4.7	4.3	4.4	4.2	4.9	4.7	4.4	1.8	0.4		
1992	:		21	100	60	29	43	39	97	100	77	6	
	:		3.1	2.1	1.9	3.8	3.7	3.7	2.8	0.5	1.3	4.7	
1993	:			25	8	2	29	54	87	81	23		1
	:			3.7	4.7	4.8	3.6	3.7	2.6	2.6	1.6		4.8
1994	:		2		<1		61	80	63	16	46		
	:		4.8		4.9		4.0	3.7	3.4	4.3	3.2		
1995	:							2	61	6			
	:							4.8	3.0	4.6			
1996	:	15	n/a				8	63	94	89	15	18	
	:	4.1					4.8	3.4	2.0	2.5	3.7	4.3	
1997	:						14	74	88	83	44	2	11
	:						3.6	3.1	3.3	2.4	2.2	4.7	4.5
1998	:												
	:												
1999	:					n/a	<1	48	20	43	100	93	39
	:						4.9	3.0	3.1	1.8	1.7	3.8	3.8
2000	:	4	11				11	61	28	1			12
	:	4.7	3.9				2.9	2.9	2.7	4.8			4.7
2001	:	5					69	75	73	61			n/a
	:	4.7					2.5	2.3	3.0	2.9			
Average ³	:	5	6	14	6	6	27	34	37	36	23	3	4

1. Excursion rate is the number of hourly average DO measurements from the DWR monitoring station below 5.0 mg/L divided by the total number of such measurements recorded that month, shown as a percent.

2. The minimum hourly average dissolved oxygen measurement for the month in mg/L

3. Average excursion rate is not the simple average of all monthly data-- it is weighted to account for months that had only partial data sets

2.0 NUMERIC TARGETS

The numeric targets for this TMDL are simply the numeric DO objectives cited in *The Water Quality Control Plan for the Sacramento River Basin and the San Joaquin River Basin, Fourth Edition*, hereafter referred to as the Basin Plan (CVRWQCB, 1998).

2.1 Basin Plan Dissolved Oxygen Objectives

There are two parts to the Basin Plan DO water quality objective that apply to the lower San Joaquin River (SJR):

5.0 mg/L at all times on the SJR within the Delta (excluding SJR west of Antioch bridge)

This objective first appeared for all waters of the Delta in the *Interim Water Quality Control Plans for the Sacramento-San Joaquin Delta* adopted in 1967 (CVRWQCB, 1967). It was adopted again into the first edition of the Basin Plan in 1975 (CVRWQCB, 1975) and remains in the current edition. The SJR west of Antioch is governed by the Basin Plan for the San Francisco Bay Regional Water Quality Control Board and is downstream of the impairment addressed by this TMDL.

6.0 mg/L minimum between Turner Cut and Stockton from September 1 through November 30

This objective was first adopted by the State Water Resources Control Board (SWRCB) in the 1991 *Water Quality Control Plan for Salinity, San Francisco Bay / Sacramento-San Joaquin Delta Estuary* (SWRCB, 1991). This objective was adopted into the third edition of the Basin Plan in 1994 (CVRWQCB, 1994) and remains in the current edition. The objective was adopted by the SWRCB again in their 1995 *Water Quality Control Plan for the San Francisco Bay / Sacramento-San Joaquin Delta Estuary* (SWRCB, 1995). The 5.0 mg/L objective applies at all other times and locations not covered by the 6.0 mg/L objective.

2.2 Impact on Beneficial Uses

The CWA Section 303(d) listing for low DO in the DWSC is based on impairment to its fisheries-related beneficial uses. These beneficial uses are established in the Basin Plan as follows:

- warm freshwater species (striped bass, sturgeon, and shad) migration and spawning (WARM MIGR and WARM SPWN)
- cold freshwater species (salmon and steelhead) migration (COLD MIGR)
- warm and cold freshwater species habitat (not including anadromous species) (WARM and COLD)

The 1967 Interim Basin Plan stated, “migratory salmonids require at least 5.0 mg/L dissolved oxygen, as do the resident game fishes. Striped bass and other fishes also require at least 5.0 mg/L dissolved oxygen to successfully propagate” (CVRWQCB, 1967). Prior to the latest version, the USEPA Water Quality Criteria suggested a 5.0 mg/L criterion (USEPA, 1976). This criterion was typically interpreted as being applicable at all times and places except for low flow conditions worse than the lowest seven-day flow with a ten-year return frequency (7Q10).

Likewise, a study in the San Joaquin River found that the adult salmon migration run upstream past Stockton did not become steady until DO concentrations were above 5 ppm (mg/L) (Hallock, *et al.*, 1970). This study did not discuss any time averaging or considerations of spatial variability. In 1986 the USEPA revised its suggested criterion to include a range of values and averaging periods based on life stages present (USEPA, 1986).

The 6.0 mg/L objective included in the 1991 and 1995 SWRCB water quality control plans was intended to protect fall-run Chinook salmon spawning migration. The technical basis for the objective was an agreement reached in 1969 between the California Department of Water Resources (DWR), California Department of Fish and Game, U.S. Bureau of Reclamation (USBR), and the predecessor to U.S. Fish and Wildlife Service to take specific actions to maintain the dissolved oxygen content in the DWSC above 6 ppm (mg/L). This agreement called for the installation of a temporary rock barrier at the head of Old River to increase San Joaquin River flows past Stockton, thus improving DO levels (SWRCB, 1991,1995).

3.0 SOURCE AND LINKAGE ANALYSIS

3.1 Overview

Numerous studies over the last several years have provided significant data and information on the causes of the DO impairment. The most recent round of studies were peer-reviewed in June 2002 by an independent science panel and summarized in the Synthesis Report (Lee and Jones-Lee, 2003). The three main contributing factors to the DO impairment identified in these studies are as follows:

- Loads of oxygen demanding substances from upstream enter the DWSC where they oxidize and exert an oxygen demand.
- The DWSC geometry reduces the capacity of the DWSC to assimilate loads of oxygen demanding substances by (i) reducing the efficiency of natural re-aeration mechanisms and (ii) magnifying the effect of oxygen demanding reactions.
- Reduced flow through the DWSC reduces the assimilative capacity by reducing upstream inputs of oxygen to the DWSC and increasing the residence time for oxygen demanding reactions that further impact DO concentrations.

3.2 Oxygen Demanding Substances

Loads of oxygen demanding substances from upstream enter the DWSC where they oxidize and exert an oxygen demand in the water column. The main upstream sources of oxygen demanding substances are categorized into three groups:

- Oxygen demand discharged from the City of Stockton Regional Wastewater Control Facility (RWCF)
- Algae loads from the watershed upstream of the DWSC
- Other potential sources

Empirical data from numerous studies have shown the relationship between DO concentrations and loads of oxygen demanding substances entering the DWSC. More studies are required,

however, to better understand the chemical, biological, and physical mechanisms linking upstream sources of oxygen demanding substances to oxygen demand in the DWSC.

3.2.1 City of Stockton Regional Wastewater Control Facility

The primary point source of oxygen demanding substances contributing to the DO impairment is the discharge of oxygen demanding substances from the City of Stockton Regional Wastewater Control Facility (RWCF). Constituents in RWCF effluent that contribute to the DO impairment include, but are not limited to, carbonaceous biological oxygen demand (CBOD), ammonia, and organic nitrogen. These are biodegradable substances that oxidize in the water column of the DWSC and reduce the amount of DO available.

Extensive box model calculations were presented in the Synthesis Report that began to quantify the relative loading of oxygen demand to the DWSC from RWCF constituents versus algae and other substances (Lee and Jones-Lee, 2003, pgs. 44-55). Calculations quantifying the relative contribution from RWCF effluent CBOD and ammonia concentrations were also made (Lee and Jones-Lee, 2003, pgs. 41-53). A more detailed discussion of those calculations appears in Section 4.4.1, where they will be used as the basis for preliminary wasteload and load allocations to the RWCF and algae.

Some data and analysis is also available on the rate at which these substances oxidize in the laboratory. The relative rate at which these compounds oxidize in the DWSC, however, and the influence of numerous environmental variables on these oxidation mechanisms is not well understood. Additional field studies and detailed modeling of these oxidation mechanisms in the DWSC is required before it can be quantified how much of the BOD discharged from the RWCF actually oxidizes and contributes to the DO impairment in the DWSC.

3.2.2 Algae Loads

The primary non-point source of oxygen demanding substances into the DWSC is algae from the SJR watershed upstream of the DWSC. Algae grown in the SJR watershed flows into the DWSC, where, it is hypothesized, light conditions for sustaining algal growth in the DWSC are not as good as they are in the shallower upstream reaches of the San Joaquin River. Specifically, the deeper geometry of the DWSC reduces the lighted surface area to volume ratio of the SJR, reducing the amount of light available to support algal photosynthesis. As a result, a portion of the algae begins to respire, consuming rather than generating oxygen, and eventually dies; the decaying biomass exerting additional oxygen demand (Foe, *et al.*, 2002, pg. 16).

Analysis of data collected between October 1999 and November 2001 has found a strong correlation between indicators of algae biomass (chlorophyll-a and phaeophytin concentrations) and biological oxygen demand (BOD) in samples collected at Maze Blvd., Vernalis and Mossdale on the SJR. The results of this analysis were consistent with those from previous studies that found algae and their byproducts are responsible for most of the oxygen demand in the SJR from (Foe, *et al.*, 2002, pg. 18). Further analyses also found a strong correlation between increased concentrations of chlorophyll-a upstream at Mossdale and decreased DO concentrations in the DWSC upstream (Foe, *et al.*, 2002, pg. 20).

The responsibility for current algae concentrations in the SJR appears to rest with increased use of fertilizers and agricultural activities in the watershed. Data and literature indicate that current average nitrate concentrations in the San Joaquin River at Vernalis have risen dramatically since the early 1950s, while phosphorus and ammonia have not. This increase tracks with the increased use of nitrogen-based agricultural fertilizers, increased cultivation, and increased use of subsurface tile drainage over the same period in the San Joaquin Valley (Kratzer and Shelton, 1998). Concentrations of nitrogen compounds in the San Joaquin River that support algae growth are currently about 10 to 100 times higher than limiting values. With a surplus of nutrients in the San Joaquin River, the algae growth appears to be limited only by the light penetration characteristics of the water (Lee and Jones-Lee, 2003, pg.41).

Statistical analysis and simple growth modeling using chlorophyll-a concentrations at numerous locations along the SJR suggest that the main sources of algae in the SJR are from Salt Slough, Mud Slough, and the San Joaquin River upstream of Lander Ave. These upper watershed tributaries were estimated to account for 80 to 90 percent of the chlorophyll load at Mossdale. The large contributions from these tributaries appear to be related not only to their high initial loads of algae into the SJR, but also the longer residence times that allow algae concentrations to increase as these loads move downstream (Foe, *et al.*, 2002, pg. 22 - 26). There remain a number of questions, however, related to algae growth and removal mechanisms that make it difficult to definitively quantify the relative contribution of algae from different sources in the watershed. One question deals with the relative impact of reduced flows from the three main eastside tributaries on algae concentrations and their travel times in the SJR. Of particular uncertainty is the fate of algae in the SJR between Mossdale and the DWSC (Foe, *et al.*, 2002, pg. 20 – 22).

3.2.3 Other Potential Sources

Other point or non-point sources of oxygen demanding substances may exist in the watershed upstream of the DWSC. These sources may contribute to oxygen demand in the DWSC, however, further study of their linkages to the impairment are required before wasteload or load allocations can be considered further. Following is a discussion of three potential sources that warrant further investigation.

Municipal wastewater discharges: Wasteloads of oxygen demanding substances (e.g. carbonaceous biological oxygen demand, ammonia, and organic nitrogen) from upstream municipal wastewater discharges, other than the City of Stockton, may contribute to oxygen demand in the DWSC if they are not fully oxidized in the watershed before entering the DWSC. A better understanding of the inputs from these facilities and their upstream oxidation mechanisms is required before an assessment of their impact on the DWSC can be made.

Stormwater discharges: The SWRCB has included five urban waterways in the vicinity of the City of Stockton on their CWA Section 303(d) list as impaired for low DO. Stormwater discharges containing oxygen demanding substances from adjacent urban and industrial areas have been implicated in these DO impairments. These five waterways are tributary to the impaired portion of DWSC. If not fully oxidized in these waterways, remaining oxygen demanding substances may contribute to the DO impairment in the DWSC. A better understanding of the inputs and oxidation mechanisms in these urban waterways is required

before an assessment of their impact on the DWSC can be made. The potential impact of storm water discharges directly into the SJR upstream or within the DWSC must also be considered.

Ammonia from upstream impaired water bodies: Loads of ammonia into the DWSC become a major source of oxygen demand as they are oxidized in the DWSC. The SWRCB has included Avena Drain, Lone Tree Creek and Temple Creek in the French Camp Slough sub-watershed on the CWA Section 303(d) list as impaired for ammonia. To the extent that there are ammonia loads to the DWSC from these sub-watersheds, load allocations will need to be considered. A better understanding of the ammonia inputs and oxidation mechanisms in these tributary water bodies is required before an assessment of their impact on the DWSC can be made.

Other potential sources may exist, which have not yet been identified. A goal of the monitoring program described in Section 5 is to identify the location and magnitude of potential sources.

3.3 Stockton Deep Water Ship Channel Geometry

The DWSC geometry is an important contributing factor because it reduces the assimilative capacity of the DWSC for loads of oxygen demanding substances by reducing the efficiency of natural re-aeration mechanisms and magnifying the effect of oxygen demanding reactions.

The Stockton Deep-Water Ship Channel (DWSC) was constructed in phases beginning in the late 1800s to allow for the navigation of ocean-going vessels upstream on the San Joaquin River to the Port of Stockton for loading and unloading. The Port of Stockton is located on approximately 1,500 acres, just west of the City of Stockton (see Figure 1-1). The channel is approximately 500 feet wide where the San Joaquin River enters the DWSC at the eastern edge of Rough & Ready Island. It increases to a width of approximately 1,000 feet at Turner Cut, approximately seven miles downstream from Rough & Ready Island. The current design depth of the DWSC is 35 feet below mean lower low water (MLLW). Upstream of the DWSC, the San Joaquin River ranges in width from 150 to 250 feet and is relatively shallow, ranging from five to ten feet in depth (Jones & Stokes, 1998).

Any channel deepening or maintenance dredging in the DWSC is performed by the U.S. Army Corps of Engineers (USACOE). The Port of Stockton performs maintenance dredging of the berths at the Port of Stockton and would be the lead agency for any future berth deepening.

There are three mechanisms in the DWSC that are hypothesized to contribute to the DO impairment. The first is that the deeper and wider DWSC cross-section increases water residence time, which allows for more imported organic material to oxidize and exert oxygen demand in the DWSC. Second, the deeper DWSC decreases the relative proportion of the water column in contact with the atmosphere, thereby reducing the efficiency of natural surface re-aeration. Finally, the deeper DWSC decreases the relative proportion of the water column that has sufficient light to support algae photosynthesis. As a result, a portion of the algae begins to respire (consuming rather than generating oxygen). In turn, a portion of these compromised algae eventually die and their decaying biomass exerts additional oxygen demand in the water column (Foe, *et al.*, 2002, pg. 16)

During the summers of 1999 through 2001, the City of Stockton made weekly DO measurements at a series of locations upstream and through the DWSC. Of the 152 samples collected upstream of the DWSC, only one during that period was less than the DO objective. At the same time, 36 percent of 76 samples collected within the DWSC were below DO objectives (Foe, *et al.*, 2002, pg. 16 - 17). A link-node water quality model developed by Systech Engineering was also used to evaluate the relative impact of the DWSC geometry. Using flow and organic loading data from 1999 and 2000, the model predicted no violations of the 5 mg/L dissolved oxygen water quality objective when natural San Joaquin River dimensions were used to replace the modeled DWSC geometry (Chen and Tsai, 2001). These data and modeling results are consistent with the concept that the DWSC geometry is an important contributing factor to the DO impairment.

3.4 Reduced Flow Through the Stockton Deep Water Ship Channel

Flow in the DWSC portion of the San Joaquin River may be reduced by (i) consumptive use in the San Joaquin River watershed, and (ii) the diversion of San Joaquin River flows down Old River that result from the operation of the pumping plants at the State Water Project by DWR and the federal Central Valley Project by USBR. Extensive data supports the connection between flow rates and DO concentrations in the DWSC. Although more studies are required, reduced flow through the DWSC appears to both reduce oxygen inputs to the DWSC and increase the residence time for oxygen demanding substances to impact DO concentrations.

3.4.1 Reduced Flow at Vernalis

The hydrology of the San Joaquin River is complex and highly managed through the operation of dams, diversions, and supply conveyances. Annual discharge from the San Joaquin River watershed is considerably lower than the unimpaired runoff that would occur if there were no reservoirs or consumptive use of water. Between 1979 and 1992 the measured runoff in the basin as measured at Vernalis was 2.4 million acre-feet lower than the mean annual unimpaired discharge of 6.1 million acre-feet (USGS, 1997). The difference is due to consumptive use, attributable mostly to water use for agriculture (DWR, 1994).

Based on SJR flow data at Vernalis, the fifteen-year moving average¹ of annual discharge in the late 1990's was approximately 800,000 acre-feet lower than in the late 1940s. Almost all of this reduction in annual watershed discharge occurs during the months of April through August (Oppenheimer and Grober, 2002). Another study found the San Joaquin River flow at Vernalis reduced by 44-56 percent from pre-1944 levels between the months of April through September (Water and Power Resources Service and South Delta Water Agency, 1980).

3.4.2 Flow Split at Head of Old River

The California Department of Water Resources (DWR) and U.S. Bureau of Reclamation (USBR) both operate pumping facilities west of the City of Tracy that have a significant impact on the routing of flow in the Delta and the DWSC. As part of the State Water Project (SWP), DWR operates the Banks Pumping Plant, which supplies water for the South Bay and California Aqueducts. The Banks Pumping plant draws water from Clifton Court Forebay, which is currently permitted to divert an average of 6,680 cubic feet per second (cfs) water from the

¹ The fifteen-year moving average helps identify long-term trends that may be obscured by annual variability of discharge.

Delta. DWR is in the process of planning to increase diversions into Clifton Court Forebay from the Delta to an average of 8,500 cfs. As part of the Central Valley Project (CVP), USBR operates the Tracy Pumping Plant to supply flow for the Delta-Mendota Canal. The Tracy Pumping Plant is currently permitted to draw an average of 4,400 cfs water from the Delta.

Water is conveyed to these two pumping plants through the Delta from the Sacramento and San Joaquin Rivers via a network of man-made and natural channels, including Old River. The southeastern reach of Old River diverges from the San Joaquin River just west of Manteca, CA about 14 miles upstream of the DWSC and flows into the south Delta. The northwestern reach of Old River continues north out of the south Delta and rejoins the San Joaquin River near Disappointment Slough. When the SWP and CVP pumps are operating, the northwestern reach of Old River conveys water from the north and central Delta, while the southeastern reach of Old River conveys water from the San Joaquin River through the south Delta.

One of the effects of SWP and CVP pumping is an increase in the amount of flow that diverges from the San Joaquin at the head of Old River, thereby reducing the flow that continues in the San Joaquin River through the DWSC. As the combined SWP and CVP export rates increase relative to the San Joaquin River flow upstream of the head of Old River, the percentage of flow diverted down Old River (and away from the DWSC) increase. During periods of low flow when SWP and CVP exports are greater than San Joaquin River flows, up to 90 percent of the river flow can be diverted down Old River and away from the DWSC. When combined SWP and CVP exports are less than San Joaquin River flows, Old River flows and SJR flows through the DWSC are nearly equal (Brown and Renehan, 2001).

Beginning in 1969, with an memorandum of understanding between fishery and pumping project agencies, a temporary rock diversion barrier has been installed each fall at the head of Old River in order to increase flow in the SJR past Stockton. When the barrier is in place, an increased percentage of flow remains in the San Joaquin River and flows downstream to the DWSC. Monitoring data show that installation of the barrier in the fall usually improves DO concentrations in the lower SJR, especially in years with relatively low SJR flows. Modeling performed for Water Right Decision 1641 found that significant improvements to DO conditions in the DWSC were not achievable without the temporary barrier (SWRCB, 2000, pg. 77).

Since 1991, as part of its South Delta Temporary Barriers Project, DWR has been collecting performance data on the temporary diversion barriers. This data is being used in their planning for their South Delta Improvement Projects (SDIP). The SDIP is proposing to provide a number of permanent operable flow diversion barriers (including at the head of Old River) and other improvements that will mitigate impacts on water quality and supply from an increase of the average allowable diversion capacity into Clifton Court Forebay from 6,680 to 8,500 cfs. The draft environmental impact report for the SDIP, as required by the California Environmental Quality Act (CEQA), is scheduled for release in the fall of 2003. CVRWQCB staff will be working with DWR to ensure that adequate consideration is given to the impact of this project on the DO impairment in the DWSC.

3.4.3 Effect of Reduced Flow on Dissolved Oxygen Impairment

The nature of the relationship between reduced flow through the DWSC on the severity and spatial extent of the DO impairment is discussed in detail in the *Draft Stawman Source and Linkage Analysis for Low Dissolved Oxygen in the Stockton Deep Water Ship Channel* (Foe, *et al.* 2002). The working hypothesis of this report is that as flow at a given DO concentration (oxygen input rate) through the DWSC is reduced, less oxygen demand can be exerted on that flow before DO concentrations drop below the Basin Plan objectives. Also, the increased residence times associated with reduced flows through the DWSC are thought to magnify the affect of chemical, biological and physical mechanisms that oxidize oxygen demanding substances (Foe, *et al.*, 2002, pg. 7 - 8). This effectively reduces the assimilative capacity of the DWSC for a given load of oxygen demanding substances.

This relationship between flow and low DO is also clearly demonstrated in Figure 3-1, which plots the daily minimum DO concentrations measured at the DWR DO monitoring station at Rough & Ready Island against the net daily flow rate in the DWSC² on the same day. The plot includes 1,168 data points, one for each day between November 1995 and September 2000 that has both a minimum DO reading and a corresponding net daily flow value. For net daily flow above 3,000 cfs, there were no violations of either the 5.0 or the 6.0 mg/L Basin Plan DO objectives. Below 3,000 cfs, the DO concentrations decrease with decreasing flow. At flows below 1,000 cfs, about half of the daily minimum DO concentrations were below 5.0 mg/L.

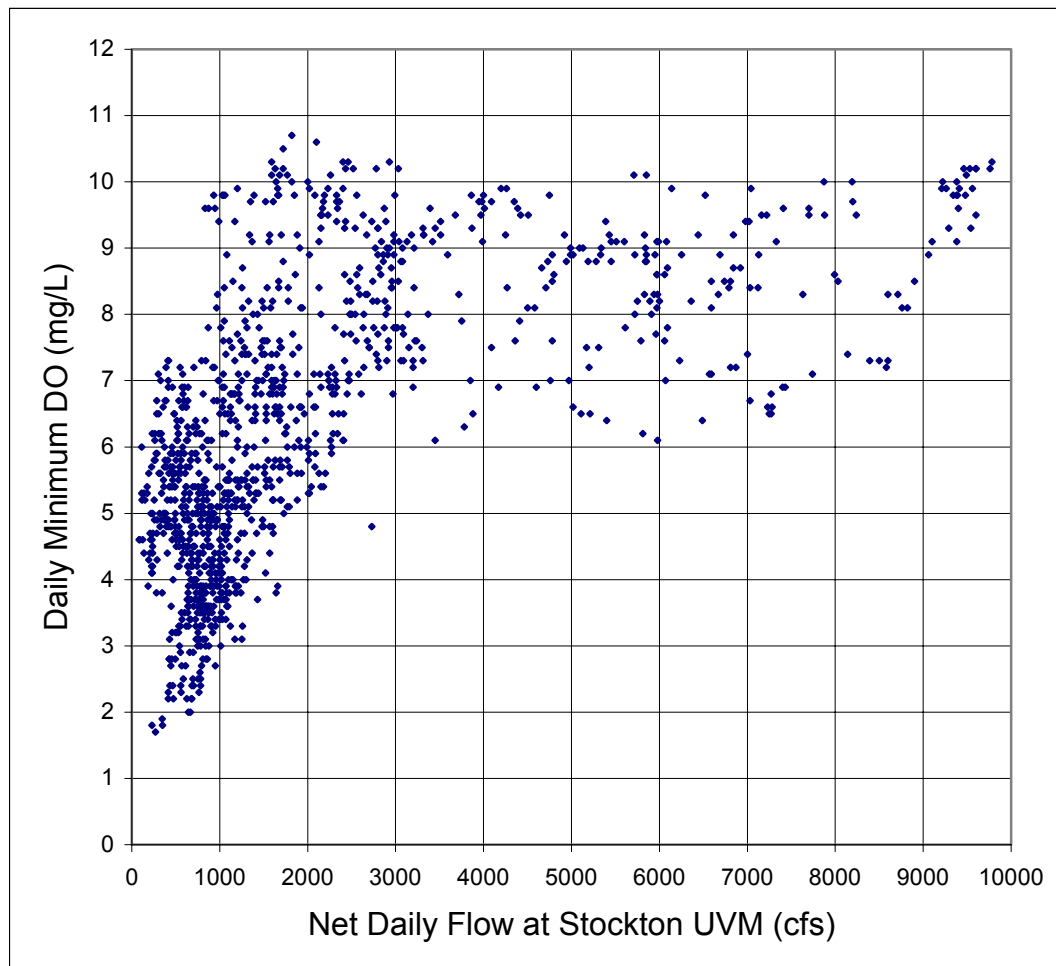
Another analysis of DWR boat cruise data found that DO concentration profiles in the DWSC appear to follow a sag profile similar to one predicted by a simple Streeter-Phelps water quality model. This analysis found the location of the low point in the sag profile moved downstream as flow increased. It also appears that reduced flow tends to increase the BOD concentrations entering the DWSC from upstream, which had the effect of increasing the severity of the impairment at the low point in the sag curve. Some of these observations were based on limited amounts of data and warrant further investigation. More data and detailed modeling in the DWSC is required (Foe, *et al.*, 2002, pgs. 9 – 15).

The rate at which flow is reduced through the DWSC also appears to be of particular concern. This can occur with sudden changes in SJR flow associated with reservoir operations and/or operation of the flow diversion barriers at the head of Old River and in the south Delta. It has been hypothesized that the higher loads of oxygen demanding substances present before a sudden decrease in flow, overload the assimilative capacity present in the DWSC after the loads are decreased. Further study of this phenomenon is needed (Lee and Jones-Lee, 2003, pg. 67).

Even with clear empirical relationships, however, more field and laboratory studies are required to better understand the effects of flow on the various mechanisms that create oxygen demand in the DWSC. Water quality modeling is then needed to understand the net effect of all these mechanisms on DO concentrations and their sensitivity to changing environmental variables (e.g. changes in flow, temperature).

² Net daily flow in the DWSC is calculated from tidal flow data collected at the USGS Stockton UVM meter, including consideration of semi-diurnal tidal periods and other tidal variations. See Brown and Renehan, 2001 for detailed description.

Figure 3-1: Dissolved Oxygen Concentrations versus Flow



4.0 WASTELOAD AND LOAD ALLOCATIONS

4.1 Overview

The CWA defines loading capacity as the greatest amount of loading that a water body can receive without violating water quality standards (40 CFR § 130.2 (f)). This is a TMDL for low dissolved oxygen and organic enrichment rather than for a single specific pollutant. The loading capacity in this TMDL is therefore expressed as an allowable rate of oxygen demand at the point of lowest DO concentration in the DWSC, such that the Basin Plan DO objectives are maintained. The loading capacity is calculated as a function of flow through the DWSC and water temperature. As discussed in Section 3, the three main contributing factors to the DO impairment in the DWSC are (i) loads of oxygen demanding substances, (ii) DWSC geometry, and (iii) reduced flows through the DWSC.

Specific allocations are developed for sources of oxygen demanding substances in the SJR watershed based on their linkage to the impairment. Although they are contributing factors, the DWSC geometry and reduced flows through the DWSC are not loads of a substance for which

loads will be allocated. Instead, these factors reduce the loading capacity available to sources of oxygen demanding substances.

Calculation of the loading capacity available for allocation to loads is based on the assumption that the impact of the two non-load related factors will be addressed by regulatory means other than effluent limitations based on wasteload and load allocations. A preliminary estimate has been made of the amount of the loading capacity that will be addressed by other regulatory means. More study of sources, linkages, and other contributing factors is required to validate the allocations and assumptions proposed here.

If another acceptable approach for developing allocations and addressing reduced loading capacity can be developed and implemented by the responsible entities, the approach taken in this initial version of the TMDL may be modified.

Section 5 presents a discussion of the proposed program of implementation for this TMDL. The program of implementation will include a description and schedule of completion for additional studies required to more accurately determine loading capacity and allocations. These studies are intended to provide the responsible entities with the information needed to develop their own acceptable solution to the problem and to provide the Regional Board with the information it needs to refine the TMDL described in this report.

4.2 Loading Capacity and TMDL

4.2.1 Loading Capacity

The solubility of oxygen in water, at relatively constant atmospheric pressure and salinity, is a function of temperature. At standard atmospheric conditions and with typical San Joaquin River salinity concentrations, the maximum concentration of DO in water ranges from about 10.0 mg/L at 15°C (59°F) to about 7.9 mg/L at 27°C (81°F). This represents a typical range of seasonal low and high temperatures experienced in the DWSC.

Below the saturation concentration, DO concentrations in the DWSC are affected by the relative rate of chemical and physical mechanisms that remove oxygen from the water column (oxygen demand) versus those that add oxygen (re-aeration). At any particular point in the river, when the rate of all oxygen demanding mechanisms are greater than the rate of all the re-aeration mechanisms, DO concentrations decrease (and visa versa). Oxygen demand and re-aeration are expressed in units of mass per unit time, and for this TMDL will be expressed as pounds of oxygen per day.

The total theoretical loading capacity of the DWSC for oxygen demanding substances, LC_T , is the amount of oxygen demand that can be present at any point in the DWSC such that Basin Plan DO objectives are not violated. This does not include consideration of a margin of safety or other factors that reduce loading capacity. In equation form, loading capacity, LC_T , is given by:

$$LC_T = \{DO_{sat} - DO_{obj}\} \times Q_{DWSC} \times 5.4 \quad (4-1)$$

where DO_{sat} is the saturation dissolved oxygen concentration, which is itself a function of water temperature, in milligrams per liter; DO_{obj} is the applicable Basin Plan dissolved oxygen objective in milligrams per liter; Q_{DWSC} is the net daily flow rate through the DWSC³ in cubic feet per second; and 5.4 is a unit conversion factor that provides LC_T , in terms of pounds of oxygen per day. From the above equation, it can be seen that LC_T is a function of flow through the DWSC and temperature (to the extent that temperature affects DO_{sat}). Although temperature will be a factor in determining LC_T , because it is driven primarily by seasonal variation, it will not be a factor that is allocated responsibility for mitigating the DO impairment. Figure 4-1 (a) provides a plot of the LC_T (based on Equation 4-1) as a function of flow at four different temperatures when the 5.0 mg/L DO objective is applicable. Figure 4-1(b) provides the same plot of LC_T when the 6.0 mg/L objective is applicable.

4.2.2 Margin of Safety

The CWA and USEPA regulations require a margin of safety to account for uncertainty concerning the relationship between wasteload and load allocations and water quality. For this TMDL, the margin of safety will be stated explicitly as a percentage of the loading capacity for a given flow rate. The margin of safety will consider both the measurement accuracy of parameters used to determine loading capacity and an estimate of technical uncertainty associated with the current understanding of the various sources and their linkages to the impairment.

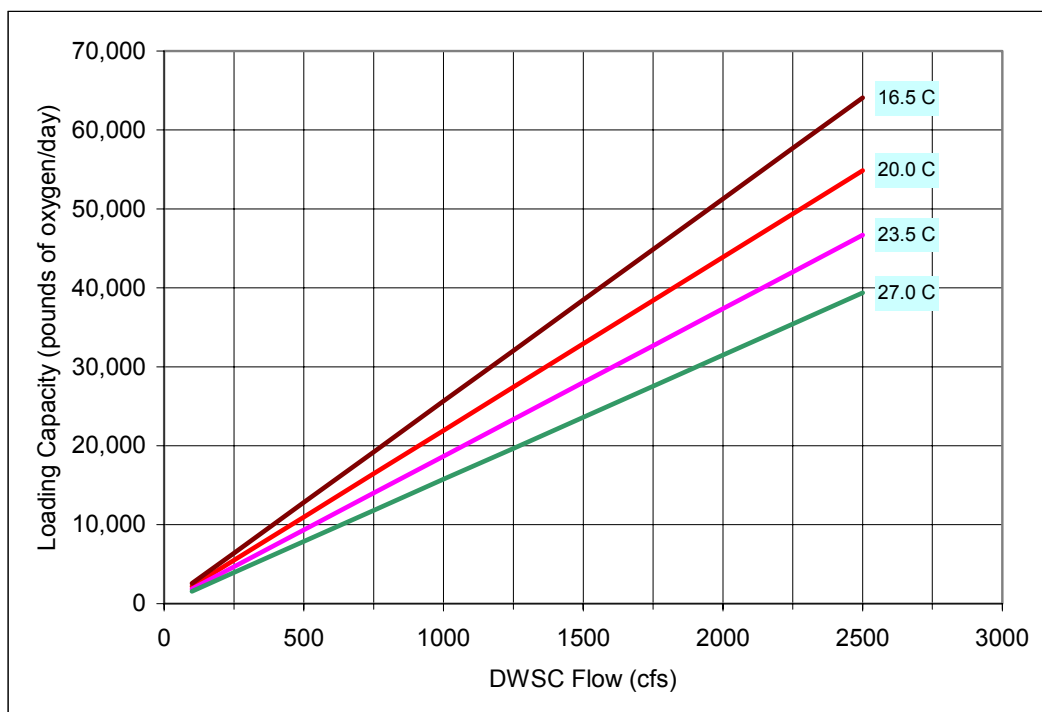
Flow rate through the DWSC is the key parameter needed to determine the total theoretical loading capacity (LC_T) in the DWSC. The only direct measurement of flow through the DWSC occurs at an ultrasonic velocity meter (UVM) and stage recorder installed immediately upstream of the Stockton RWCF, about 1.5 miles upstream of the DWSC. This is a U.S. Geological Survey (USGS) facility that was built in cooperation with the City of Stockton in the summer of 1995. The flow is calculated at this location from the UVM velocity and tidal stage, which is recorded every 15 minutes on a data logger at the facility. Net daily flow is calculated from this data with adjustments made to account for the semi-diurnal tidal period and other tide related variations (Brown and Renehan, 2001).

An estimate of accuracy of the net daily flows determined from measurements at this UVM is believed to be in the range of 20 to 40 cfs. At low flow rates of 200 cfs or less, when the low DO impairment tends to be most severe, the possible error rate for flow measurements is 10 to 20 percent (Lee and Jones-Lee, 2000, pg.26). The only other variable in the determination of loading capacity is temperature (as it affects the DO saturation concentration). Measurement of water temperature is considerably more accurate than measurements of flow and should be adequately addressed by this margin of safety. Therefore, a margin of safety of 20 percent will be used to account for the measurement error of parameters included in the calculation of loading capacity.

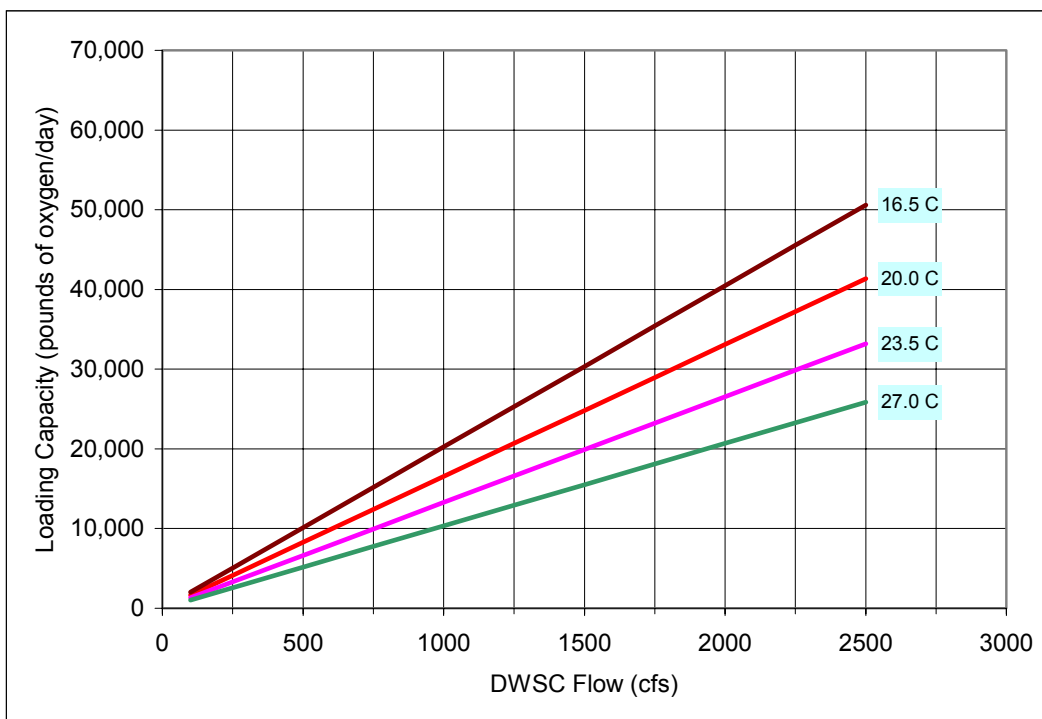
³ Net daily flow in the DWSC is calculated from tidal flow data collected at the USGS Stockton UVM meter, including consideration of semi-diurnal tidal periods and other tidal variations. See Brown and Renehan, 2001 for detailed description.

Figure 4-1: Loading Capacity (LC_T) Versus Flow and Temperature

(a) with 5.0 mg/l objective and varying temperatures



(b) with 6.0 mg/l objective and varying temperatures



Due to the need for further technical study on the sources, linkages, and potential mitigation measures for their impact, there is a significant amount of technical uncertainty surrounding the allocation of wasteloads and loads to sources of oxygen demanding substances and the assumptions regarding the extent to which the impact of non-load related factors can or will be mitigated. Based on professional judgment, a 20 percent margin of safety will be used to account for this technical uncertainty. This margin of safety can be reevaluated for the final phase of the TMDL, based on results of the various studies performed in the initial phase.

To account for flow measurement error and technical uncertainty, a combined 40 percent margin of safety is proposed to determine how much loading capacity may be allocated to loads:

$$MOS = 0.4 \times LC_T \quad (4-2)$$

This margin of safety does not include a factor for future growth. Any future project in the watershed that has the potential to contribute loads of oxygen demanding substances, or has the potential to reduce loading capacity in the DWSC, will have to evaluate and mitigate the entire impact of their proposed project as required by applicable State and Federal regulations.

4.2.3 Total Daily Maximum Load

The TMDL is equal to the loading capacity (LC) of the water body. The loading capacity available for this TMDL, however, must be reduced to account for the effects attributable to DWSC geometry and reduced DWSC flow:

$$TMDL = LC = LC_T - [LC_{DWSC} + LC_{Flow}] \quad (4-3)$$

where:

LC_T = the total theoretical loading capacity as described in Section 4.2.1,

LC_{DWSC} = the reduction of loading capacity associated with the DWSC geometry,

LC_{Flow} = the reduction of loading capacity associated with reduced DWSC flow.

Per 40 CFR Section 130.2, the TMDL is also the sum of all wasteload allocations for point sources ($\sum WLA$), plus the sum of all load allocations for non-point sources ($\sum LA$), plus background loads (BL), and the margin of safety (MOS):

$$TMDL = \sum WLA + \sum LA + BL + MOS \quad (4-4)$$

Background loading for oxygen demand in the DWSC is assumed to be zero and the MOS is equal to 40 percent of the LC_T as described in the Section 4.2.2. Together, $[\sum WLA + \sum LA]$ represent the amount of loading capacity available for allocation to oxygen demanding substances.

The method for determining how much of the loading capacity this TMDL will apportion to each of the three contributing factors+ is presented in the next section.

4.3 Assumptions Regarding Non-Load Related Factors

4.3.1 Impact of Non-Load Related Factors

Apportioning loading capacity between the three contributing factors is complicated by the existence of technical rationale for why each is 100 percent responsible for the low DO impairment. For example, the USACOE has argued that the impairment in the DWSC would not exist if there were no loads of oxygen demanding substances entering the DWSC from upstream (ACOE, 1990). Conversely, no DO impairment exists in the San Joaquin River upstream of the DWSC in spite of the presence of these oxygen demanding substances (Foe, *et al.*, 2002, pg. 17). It can be reasonably argued that if either of these two contributing factors were eliminated, the low DO impairment would not exist. As discussed in Section 3.4, the impact of reduced flow on the loading capacity of the DWSC under current DWSC geometry and variable loading conditions has been well documented. For given DWSC geometry and loading conditions, the impairment could be eliminated if flow through the DWSC were increased.

Based on this rationale, the theoretical total loading capacity (LC_T) at a given flow rate through the DWSC, after subtracting the margin of safety, will be apportioned equally to the entities responsible for the three main contributing factors. Combining Equations 4-3 and 4-4 provides:

$$LC_T - MOS = [\sum WLA + \sum LA] + LC_{DWSC} + LC_{Flow} \quad (4-5)$$

and,

$$[\sum WLA + \sum LA] = LC_{DWSC} = LC_{Flow} \quad (4-6)$$

Similarly, responsibility for mitigating the DO impairment will be shared equally between these three contributing factors. The assumptions regarding loading capacity apportioned to DWSC geometry (LC_{DWSC}) and reduced DWSC flow (LC_{Flow}) are addressed further in Sections 4.3.2 and 4.3.3 below. The wasteload and load allocations for the loading capacity apportioned to loads of oxygen demanding substances $[\sum WLA + \sum LA]$ are developed in Section 4.4.

4.3.2 Assumptions - Stockton Deep Water Ship Channel Geometry

The DWSC geometry reduces the efficiency of mechanisms that supply oxygen to the water column, like natural surface re-aeration and algal photosynthesis. At the same time, the DWSC geometry magnifies the impact of oxygen demanding substances (e.g. ammonia) that reduce DO concentrations in the water column. The net effect is that the DWSC reduces the loading capacity of the DWSC for loads of oxygen demanding substances.

Although the relationship between the DWSC geometry and the DO impairment is clear, further field analysis and modeling studies are required to better understand the specific mechanisms and the variables that affect them. From this, the conversion of oxygen demanding substances into oxygen demand in the DWSC can be better quantified for the development of wasteload and load allocations. Section 5 outlines the process by which further study will be conducted to fill these data gaps and to study potential mitigation measures. As further information becomes available, the relative apportioning of loading capacity between the contributing factors may be modified.

As described in Section 4.3.1, this TMDL will assume that one-third of the total theoretical loading capacity will be addressed by the entities responsible for the DWSC geometry (LC_{DWSC}). Because the DWSC geometry does not discharge any substances, however, no wasteload or load allocations are assigned to entities responsible for the DWSC geometry. Instead, the CVRWQCB can rely on other regulatory means to require mitigation for the impact of DWSC geometry. The USACOE is the primary entity responsible for the existing and any future deepening in the DWSC. The Port of Stockton is the entity responsible for any future berth deepening at its facilities along the DWSC.

As an alternative to assigning wasteload or load allocations, the CVRWQCB can rely upon its authority under Section 401 of the CWA to require that the cumulative effects of reduced loading capacity, caused by future changes in DWSC geometry, be adequately mitigated. Under CWA Section 404, any project that proposes to discharge fill or dredged material into a water of the U.S. must obtain a permit from the USACOE. If such a project has the possibility to affect water quality, project proponents must also apply for a Water Quality Certification under Section 401 of the CWA. In California, the CVRWQCB is responsible for providing these CWA Section 401 certifications (CWC § 3830-3869), which are enforceable orders under California law. In order to issue a CWA Section 401 certification, the CVRWQCB must find that the project will, in accordance with the Basin Plan, protect beneficial uses, comply with numeric water quality objectives, and not violate anti-degradation policy of State Water Board Resolution No. 68-16. The CVRWQCB may impose conditions in a CWA Section 401 certification to comply with the CWA, CWC and other applicable law, as necessary. For future projects that propose to alter the DWSC geometry, adequate mitigation for any negative impacts on loading capacity must be demonstrated before the CVRWQCB can issue a CWA Section 401 certification. In addition to CWA Section 401 certifications, the CVRWQCB can issue waste discharge requirements for dredging operations.

CVRWQCB authority to require mitigation for the existing DWSC geometry is being investigated. The USACOE has already attempted to provide some level of mitigation for past DWSC geometry alterations. Between 1984 and 1987, the DWSC was deepened from 30 feet below mean lower low water (MLLW) to 35 feet MLLW. As part of their National Environmental Policy Act (NEPA) documentation for that project, the USACOE performed modeling that estimated the deepening could reduce loading (assimilative) capacity by as much as 2,500 pounds of oxygen per day (USACOE, 1990). To mitigate this impact the USACOE constructed and operates a jet aeration system in the DWSC near where the San Joaquin River enters the DWSC at Channel Point. The jet aeration system installed by the USACOE is designed to diffuse up to 2,500 pounds per day of oxygen into the water column and is operated between 1 September and 30 November each year when DO concentrations measured at the DWR Rough & Ready Island DO monitoring station are at or below 5.0 mg/L (Nichol and Slinkard, 1999). Mitigation of the impact on loading capacity caused by the prior deepening of the DWSC to 30 feet MLLW has not been addressed by the USACOE.

4.3.3 Assumptions - Flow in the Stockton Deep Water Ship Channel

The impact of reduced flow on the loading capacity of the DWSC has been well documented under current DWSC geometry and variable loading conditions. As flow into the DWSC at a

given DO concentration is reduced, less oxygen demand can be exerted on that flow before DO concentrations drop below the Basin Plan objectives. It has also been hypothesized that there is an additional impact related to increased DWSC residence times. With increased residence time, the impact of oxygen demanding substances on DO concentrations is magnified, effectively reducing the loading capacity further.

Although the empirical relationships between reduced flow through the DWSC and the DO impairment are clear, further field analysis and modeling studies are required to better understand the specific oxidation mechanisms, and the variables that affect them, both within the DWSC and upstream. The effect of sudden changes in flow rates on both DWSC and upstream mechanisms also needs to be studied. From this, the conversion of oxygen demanding substances into oxygen demand in the DWSC can be better quantified for the development of wasteload and load allocations. Section 5 outlines the process by which further study will be conducted to fill these data gaps and to consider potential mitigation measures that may be required. As further information becomes available from these studies, the relative apportioning of loading capacity between the contributing factors may be modified.

As described in Section 4.3.1, this TMDL will assume that one-third of the total theoretical loading capacity will be addressed by entities responsible for reduced flow in the DWSC (LC_{Flow}). Because reduced flow does not discharge any substances, no wasteload or load allocations are assigned to responsible entities. Instead, the SWRCB can use its water rights authority and, in some cases, the CVRWQCB or SWRCB can use its CWA Section 401 water quality certification authority to require mitigation based on this TMDL. Numerous entities are responsible for upstream diversions and consumptive use that reduce flow in the DWSC.

The activities that affect flow in the DWSC fall under two categories: (i) consumptive use in the San Joaquin River watershed, and (ii) the diversion of San Joaquin River flows down Old River that result from the operation of the State Water Project (SWP) by DWR and the federal Central Valley Project (CVP) by USBR. Following is a brief discussion of the SWRCB and CVRWQB authorities over activities in these two categories.

Reduced San Joaquin River Flows:

There are currently no minimum required flows in the San Joaquin River past the head of Old River through the DWSC or requirements that water right permit holders provide any mitigation for the DO impairment. The SWRCB adopted Water Right Decision 1641 (D-1641) in December 1999, among other things, to allocate responsibility for achieving water quality objectives contained in the 1995 *Water Quality Control Plan for the San Francisco Bay / Sacramento-San Joaquin Delta Estuary* (Bay-Delta Plan) to water right holders whose diversions affect the beneficial uses in the estuary (SWRCB, 2000). After considering extensive testimony and analysis, the SWRCB decided in Section 9.3 of D-1641 that:

“...the SWRCB will not take any water right action to meet the (Bay-Delta Plan) DO objectives at this time. The RWQCB should determine effluent limits based on TMDL results. The SWRCB will wait until the RWQCB has established a TMDL and has implemented it before taking further action to achieve the (Bay-Delta Plan) DO objectives.” (SWRCB, 2000, pg. 79).

CVRWQCB staff intends to propose for adoption by June 2004, the TMDL and program of implementation. The TMDL, however, will likely rely upon the SWRCB to take appropriate action to address the impacts of reduced flow in the DWSC that are integral to successful implementation.

In addition to providing this TMDL, the CVRWQCB anticipates consulting with the SWRCB Division of Water Rights during the preparation of water right permits and decisions that have the potential to affect the DO impairment in the DWSC.

South Delta Improvements Project

DWR is in the planning process for their South Delta Improvement Project (SDIP). This project is intended to increase the maximum allowable diversion capacity into Clifton Court Forebay, from which the State Water Project pumps its water. At the same time it allows increased diversion, the SDIP intends to provide for adequate water supply and improved water quality in the South Delta and DWSC. One of the alternatives being considered as mitigation for the effects of increased diversion is the installation of operable flow control barriers at the head of Old River and other locations in the south Delta. These barriers will act to reduce the amount of SJR flow being diverted down Old River towards the pumps and away from the DWSC.

In Section 9.2.1 of D-1641, the SWRCB stated that:

“Flow moving past Stockton is the largest single controllable factor that affects DO. Although the 1995 Bay-Delta Plan contains flow objectives for the San Joaquin River at Vernalis, modeling shows that implementation of the 1995 Bay-Delta flow objectives alone will not significantly improve DO concentrations at Stockton. A barrier at the head of Old River can increase flows in the San Joaquin River at Stockton by reducing the proportion of flow that enters Old River. If a head of Old River barrier is constructed and is operated in conjunction with implementing the 1995 Bay-Delta flow objective, DO should improve. (SWRCB, 2000, p. 77).

After further discussion of operational and other considerations, the SWRCB concluded Section 9.2.1 by stating that:

“...this decision does not require the construction of permanent barriers in the southern Delta channels. Nevertheless, the SWRCB encourages the parties involved in constructing and regulating the barriers to consider the effects of the barriers on DO and to make their best efforts to achieve the benefits of the barriers to DO while avoiding or mitigating their adverse effects.” (SWRCB, 2000, p. 78)

In addition to SWRCB water rights authority, the SWRCB or CVRWQCB has CWA Section 401 water quality certification authority over the SDIP. As the SDIP will involve dredging in some South Delta channels and construction of other in-stream structures, they will require a CWA Section 404 permit from the USACOE and a CWA Section 401 certification from the State. In order to obtain this certification, the SDIP will need to provide adequate mitigation of impacts, among other things, to DO conditions in the DWSC.

4.4 Wasteload and Load Allocations

As described in Section 4.3.1, one-third of the available loading capacity is apportioned collectively to sources of oxygen demanding substances that contribute to the impairment. This loading capacity must be allocated as wasteloads to specific point sources, and as loads to specific non-point sources [$\Sigma WLA + \Sigma LA$]. The percentage allocated to each wasteload and load is based on the current understanding of the relative current contribution of various sources. The three main sources of oxygen demanding substances to the DWSC include:

- Oxygen demanding substances discharged from the City of Stockton RWCF
- Algae loads from the watershed upstream of the DWSC
- Other potential point and non-point sources

Specific allocations are subject to later revision in this phased TMDL because of the need for further technical study on the linkage between specific sources and the impairment.

4.4.1 Relative Contribution from Different Sources

A number of studies have generated data to evaluate the impact of City of Stockton RWCF effluent and loads of algae on the DO impairment in the DWSC. These studies provide the basis for a preliminary estimate of the relative contribution of ultimate biological oxygen demand (BOD_u) loads from the RWCF and algae to the DWSC.

Evaluation of the relative loads of BOD_u from the City of Stockton RWCF discharge compared to those from upstream loads of algae was performed on 43 sampling runs during the months of August through October 1999 and June through October 2000 and 2001. The average relative contribution was found to be about 25 percent with values as high as 53.5 percent and as low as 5.4 percent (Lee and Jones-Lee, 2003, pg.44). Additional analysis of the relative contribution was performed on samples collected between June 2002 and January 2003, with additional consideration given to flow in the DWSC. The average relative contribution of BOD_u from the RWCF was 26.5 percent, 38 percent, and 58.9 percent at high, average, and low DWSC flow rates respectively during this period. It appears the relative contribution of BOD_u loads from the RWCF increases as DWSC flow, and hence relative loads of BOD_u from upstream, decrease (Lee and Jones-Lee, 2003, pg. 63). It has also been observed that the magnitude of the BOD_u load from the RWCF is seasonally variable with lower loads during the summer and early fall and higher loads during the remainder of the year. This pattern has been attributed to the way the RWCF oxidation ponds are affected by seasonal changes in temperature and duration of daylight. The relative contribution of BOD_u from the RWCF appears to be seasonally variable and affected by flow through the DWSC, however, more analysis of existing data and more extensive future sampling will be required to better define the relative BOD_u loading rates.

The analysis just described, however, only addresses the relative loading of BOD_u and does not address how the BOD_u loads from those different sources actually exert oxygen demand in the DWSC. The complexities of determining the relative contributions to oxygen demand in the DWSC are numerous. Most important is an understanding of the mechanisms by which the various carbonaceous and nitrogenous compounds are oxidized in the DWSC and how these mechanisms are affected by variables such as flow, temperature, and environmental factors.

More data and analysis are needed to understand the dynamics of certain mechanisms. Modeling is also needed to evaluate the net effect of these mechanisms on DO concentrations. The specific data needs and the studies being performed to provide this data and analysis are discussed in Section 5.

In addition to the relative contributions from algae loads and RWCF loads, there are numerous other possible point and non-point sources of oxygen demanding substances in the watershed. For reasons addressed in Section 4.4.4 below, there will be no allocation of wasteloads or loads to these other potential sources in this initial phase of the TMDL.

Based on consideration of the above study findings, 30 percent of the loading capacity apportioned to loads of oxygen demanding substances (as described in Section 4.3.1) is allocated as a wasteload allocation to the RWCF; the remaining 70 percent is a load allocation to algae loads. This is a preliminary allocation based on the current relative contribution of BOD_u loads. This allocation may be revised when more information is available regarding the relative impact of these loads on oxygen demand in the DWSC. Other potential sources of oxygen demand may be assigned allocations based on the results of future studies.

4.4.2 Wasteload Allocations

Though point sources other than the City of Stockton may discharge oxygen demanding substances, current information is not conclusive about how much these substances are oxidized in the watershed before entering the DWSC. The City of Stockton RWCF is therefore the only point source for which a waste load allocation is specified at this time. Constituents in RWCF effluent with the greatest potential to impact DO in the DWSC are carbonaceous biological oxygen demand (CBOD), ammonia, and organic nitrogen. Other RWCF effluent constituents may, however, exert minor additional oxygen demand. In June 2002, a National Pollutant Discharge Elimination System (NPDES) permit for the RWCF was adopted under Central Valley Regional Water Quality Control Board (CVRWQCB) Order No. 5-02-083, which included, among other things, effluent limits for both CBOD and ammonia.

In the allocation scheme described above, the City of Stockton RWCF will receive a wasteload allocation equivalent to 30 percent of the loading capacity, less the margin of safety, that is apportioned to loads of oxygen demanding substances. The magnitude of this 30 percent allocation is variable dependent upon the available loading capacity, which is also dependent on flow and temperature in the DWSC. With the magnitude being variable, this wasteload allocation may be less stringent, at times, than effluent limits for CBOD, ammonia, and other constituents in the existing NPDES permit. At other times, however, such as during critically low flow conditions, the magnitude of this allocation may be more stringent than effluent limits in the existing NPDES permit. During such critical conditions, the Regional Board may be willing to consider allowing participation in a load-trading program to meet the more stringent allocation. A better understanding of how specific constituents in the RWCF discharge are converted to oxygen demand in the DWSC would be required to make such a program work.

Some data gaps need to be filled before the wasteload allocation and a possible load-trading program can be finalized. A better understanding is required of the impact of the effluent on oxygen demand and the contribution of the RWCF effluent relative to other loads. The data gaps

include understanding the oxidation rates of different constituents and how much of their potential oxygen demand is contributing to the impairment. It will also be necessary to understand how other variables in the DWSC affect these oxidation mechanisms. Section 5 outlines the process by which further study will be conducted to fill these data gaps. Once all these technical issues have been addressed, the final TMDL load limits will be incorporated into an amended NPDES permit for the City of Stockton RWCF.

4.4.3 Load Allocations

Algae conveyed from sources in the San Joaquin River Watershed is the only non-point source of oxygen demanding substances in the DWSC for which a load allocation is specified at this time. As described in Section 4.4.1, seventy percent of the available assimilative capacity apportioned to loads of oxygen demanding substances is allocated to algae. Numerous mechanisms are known or are suspected of influencing the growth, transport, and decay of algae. Of particular interest are the growth dynamics of algae as it is conveyed downstream through the watershed. Better understanding of these dynamics is needed to determine how specific sources of algae, and specific sources of nutrients that contribute to algal growth, are linked to DO concentrations. Numerous data gaps must be filled before more specific load allocations can be developed. These data gaps include:

- the process by which algae loads are converted into oxygen demand in the DWSC and how much of this resulting oxygen demand is exerted in the DWSC
- how algae are generated at the various sources in the watershed
- growth dynamics between upstream sources and the DWSC
- ways to practically and effectively control algae growth in the watershed, or otherwise mitigate its effect in the DWSC

Section 5 outlines the process by which further study will be conducted to fill these data gaps and to consider potential control or mitigation measures that may be required.

Specific load allocations for algae and substances that contribute to algal growth will be assigned to upstream sources through the agricultural discharge regulatory program. These load allocations may be implemented through issuance of a Conditional Prohibition of Discharge, General or Individual Waste Discharge Requirements, or a Conditional Waiver of Waste Discharge Requirements. These and any other applicable regulatory mechanisms will be further described and evaluated in the staff report that will be prepared for the Dissolved Oxygen TMDL Basin Plan Amendment to be considered by the Regional Board in June 2004.

The Regional Board may need to consider alternate mitigation measures as a substitute for direct control of certain causative factors if on-going studies show that certain causative factors cannot be successfully controlled directly. It may also be necessary to rely on short-term alternate mitigation measures as longer-term control measures take more time to implement and become effective. If alternate mitigation measures are selected to address certain impacts, load allocations will likely need to be adjusted to consider those mitigation measures. Similar to point sources, the Regional Board may be willing to consider allowing non-point source dischargers of algae and nutrients to meet some portion of their load allocations through participation in a load-

trading program. Additional studies addressing the data gaps, as described in Section 5, will need to be completed in order to design and successfully implement such programs.

4.4.4 Other Potential Sources

Other potential point and non-point sources of oxygen demand into the DWSC may exist. Some data gaps, however, need to be filled to assess the significance of these potential sources and to determine appropriate wasteload or load allocations, if needed. In order to fill these data gaps more information is needed on the nature of oxygen demanding substances and the mechanisms that transform them as they are transported from their source to the DWSC. Similar to RWCF constituents and algae, the mechanisms by which these other loads are then converted to oxygen demand in the DWSC, and the influencing variables, need to be understood. A comprehensive study of all these potential sources and their linkages will also likely require water quality modeling both in the watershed and the DWSC. Other potential sources not listed above may be identified through the execution of the further studies or other watershed monitoring programs. Section 5 outlines the process by which further study will be conducted to fill these data gaps and to consider potential control measures that may be required.

Available information is not adequate to support allocations to other potential sources at this time. If new information becomes available that support allocations, then they will be included in the final TMDL. Depending on the source, any such allocation will then be included in NPDES wastewater or stormwater permits for the appropriate source or will be handled through the agricultural discharge regulatory program.

Potential future increases in loads of oxygen demanding substances from new sources in the watershed proposed prior to the development of a final TMDL shall be accompanied by CEQA and/or NEPA analysis that evaluates and mitigates its impact on the low DO impairment. Depending on the type of project, other State and federal regulations may require such a project's impact on the DO impairment be addressed.

5.0 TMDL PROGRAM OF IMPLEMENTATION

5.1 Background

In California, the Porter-Cologne Water Quality Control Act (CWC § 13242) requires a program of implementation for a TMDL to be included along with the TMDL when it is placed into the Basin Plan. The program of implementation must include:

- Description of actions necessary to achieve Basin Plan water quality objectives
- Time schedule for actions to be taken
- Description of monitoring to determine attainment

In April 1999, the CVRWQCB approved the Regional Bay Protection & Toxic Cleanup Plan (BPTCP), which outlined formation of a Steering Committee consisting of representatives from various agricultural, municipal and environmental stakeholder groups (CVRWQCB, 1999). The BPTCP gave the Steering Committee the opportunity to suggest its own load allocation and implementation plan to Regional Board staff for consideration in the development of the TMDL

and program of implementation. Staff worked with the Steering Committee to formulate a phased approach that addresses the realistic need for more time to gather additional information on certain sources and linkages to the DO impairment, while at the same time moving forward on making improvements to DO conditions in the DWSC. Also, more information is needed on performance and cost information for possible mitigation alternatives to bringing the DWSC into compliance with the Basin Plan DO objectives. A report summarizing the Steering Committee recommendations for a TMDL program of implementation was submitted to staff on 4 February 2003 (Ploss, 2003). The Steering Committee chose not to recommend a TMDL load allocation.

The Steering Committee plan provided a generally acceptable framework for the TMDL implementation plan that has become the basis for the program of implementation being developed by Regional Board staff. Staff is developing the details of this program of implementation to include with the TMDL in the Basin Plan Amendment scheduled for Board consideration in June 2004.

5.2 Phased TMDL and Implementation Approach

Best available science is sufficient to justify apportioning loading capacity to the three main contributing factors to the DO impairment as described in Section 4. Some sources and linkages of oxygen demanding substances and other contributing factors to the impairment, however, require further study. As such, a phased approach to this TMDL is being developed. Based on studies performed in the initial phase, a final TMDL will be developed that will provide additional refinement on wasteload and load allocations and provide other modifications, as needed, to the relative apportioning of loading capacity. These studies will also provide the technical basis for a comprehensive selection of mitigation measures that will bring the DWSC into compliance with the applicable Basin Plan DO objectives. The studies from this program of implementation will provide the cost and performance data needed for a thorough CEQA analysis of the final TMDL and its program of implementation.

Financing for these initial phase studies will come, in part, from Proposition 13 bond funds, the various responsible entities, and other State and Federal funding sources. Proposition 13 legislation allocated \$40 million toward solving the DO impairment in the DWSC. The Bay-Delta Authority (formerly CALFED) currently coordinates the administration of those funds.

5.2.1 Data Gaps

For development of the final TMDL there is a need to better quantify the impact of various wasteloads, loads, and other contributing factors on oxygen demand in the DWSC. This is needed to refine, as necessary, the wasteload and load allocations and the apportioning of loading capacity to non-load related factors. In order to fill these data gaps more information is needed on the specific mechanisms that convert oxygen demanding substances into oxygen demand in the DWSC. Field and laboratory studies will have to determine the rates of these mechanisms and the various factors that influence them. Of particular importance is how much the potential oxygen demand from various oxygen demanding substances actually gets exerted in the impaired zone of the DWSC. More information is also needed on the mechanisms that transform oxygen demanding substances as they are transported between their sources in the watershed to the DWSC. The study of these mechanisms both in the DWSC and in the watershed will require the use of computer models. This will allow all the mechanisms to be overlaid upon each other and

the study of their net effect as a function of different environmental variables. In addition to the above, monitoring in the watershed combined with computer modeling must be used to determine if other potential sources of oxygen demanding substances are having a significant impact on the DO impairment.

The understanding of the specific mechanisms and their net effect is also important for the development of a comprehensive suite of mitigation and control measures that will bring the DWSC into compliance with the Basin Plan DO objectives. There is an additional need to understand the redirected impacts of potential mitigation or control measures on other beneficial uses in the DWSC or further downstream. Cost and performance data for potential mitigation or control alternatives is also required for a thorough CEQA analysis of alternatives for the final TMDL program of implementation. Some specific data gaps associated with developing a solution to the impairment include, but are not limited to, the following:

- understanding the impact of the spatial distribution and intensity of the impairment in the DWSC; important for designing any aeration system designed to provide mitigation in the DWSC
- collection of cost and performance data on possible aeration and non-aeration alternatives
- understanding growth dynamics of algae as it moves down through the watershed; understanding these dynamics will determine the relative impact on the DO impairment from control measures applied to different sources
- to the extent that controlling sources of algae will be effective in mitigating the impairment, more study is required to identify specific ways to practically and effectively control algae growth in the watershed
- further study of the potential redirected effects of proposed mitigation/control measures that will have to be performed to ensure that there is no unintended negative impact of those measures on other beneficial uses in the watershed or downstream.

This is a general, and not necessarily complete discussion of the data gaps for developing the final TMDL and program of implementation. An extensive and detailed discussion of the data gaps identified by the various researchers and peer-reviewers involved in previous studies is included in the Synthesis Report (Lee and Jones-Lee, 2003, pg. 126). Also, as discussed in Section 5.3.3, a technical study plan will be developed to prioritize these data gaps and develop a strategy for performing the required studies.

5.3 Plan Outline

The program of implementation will provide for further study to fill in the data gaps described above, but at the same time initiates an aeration demonstration project that will begin to improve DO conditions in the DWSC. The first round of studies to be included in the initial phase of the program of implementation are the Upstream Studies, Aeration Demonstration Project and Non-Aeration Alternatives Studies. Also, a TMDL Program Coordinator will be funded during the initial phase. Based on the results of these studies, further research on specific mitigation measures may be needed.

5.3.1 Upstream Studies

The goal of the upstream studies is to determine the sources of nutrients, algae, and other oxygen demanding materials from individual tributaries and sub-watersheds to the upper San Joaquin River. Flow and water quality monitoring will be conducted to quantify upstream loads. Dye studies will be conducted to understand travel times and dilution factors for upstream loadings and a water quality model will be used to simulate the various physical, biological and chemical transformation mechanisms in the San Joaquin River. These studies will be used to characterize the transformation and fate of algae and other oxygen demanding materials between their sources in the watershed and the DWSC.

After determining the sources and transformation mechanisms for oxygen demanding substances, the studies will attempt to understand whether controlling the sources of these substances will translate into an actual improvement in the DO impairment. An understanding of how much benefit will be achieved through source control is needed to assess the extent to which source control should be used in implementation.

These studies are important not only for the development of a technically defensible load allocation and solution to the impairment, but also to gain the confidence of upstream stakeholders that any required control measures will actually be effective in solving the problem. Upstream stakeholders from both the west and east sides of the watershed have demonstrated interest and willingness to organize and perform these upstream studies. The contracting process for these upstream studies will be administered by the Bay-Delta Authority using Proposition 13 bond funds.

5.3.2 Aeration Demonstration Project

This is a two-phased project that starts with a small-scale feasibility study of different aeration technologies that may be effective in the DWSC. This first phase will also include the design and deployment of a monitoring network to measure the impact of aeration on DO concentrations in the DWSC. Once the preferred technologies are identified by the feasibility study, the next phase of the project will be the construction and operation of a large-scale demonstration project using the aeration technologies determined most effective in the DWSC. The purpose of this large-scale project is twofold. First, the purpose is to collect performance and cost data for consideration in development of the final phase of the program of implementation. The second purpose is to begin improving DO conditions prior to development and implementation of the final phase.

The demonstration project will be designed and adaptively managed to meet a performance goal that would be established as part of the feasibility phase of the project. The performance goal will be established at a level that will begin to significantly improve DO conditions in the DWSC. The construction of the aeration demonstration project will be financed by the Proposition 13 funds as administered by the Bay-Delta Authority. The cost of operating, maintaining and monitoring the aerators would be shared by the various responsible entities whose contributing factors are determined appropriate for mitigation by aeration. An assurance agreement providing commitment by the various responsible entities to cover these costs would need to be in place before the aerators are built with Proposition 13 funds.

5.3.3 Non-Aeration Alternatives Studies

Aside from aeration, there will be other mitigation measures that merit further evaluation to determine their potential effectiveness and cost. Some of these proposed mitigation measures may directly control the contributing factors (i.e. source controls), and others may provide alternate means of mitigating contributing factors. The most promising non-aeration mitigation alternatives will be studied on a parallel track with aeration alternatives.

The first step for the non-aeration alternatives studies will be to develop a comprehensive technical study plan based on current understanding of the sources, linkages, and data gaps identified by previous studies. Development of this study plan will include further input and prioritization from a round of stakeholder workshops. This study plan will organize and prioritize a comprehensive list of data gaps and non-aeration mitigation measures that require further study and present a strategy for addressing them. This study plan may be useful as the basis for a research proposal solicitation from the Bay-Delta Authority, SWRCB or other funding sources.

Although Proposition 13 and other public funding sources are available for these studies, it is ultimately the responsibility of those entities that are found to be causing excess algae growth to provide the resources necessary to evaluate and implement acceptable control measures. The Regional Board may use its authority under CWC Section 13267 to require upstream dischargers to provide technical or monitoring reports, as necessary.

5.3.4 TMDL Program Coordination Team

The task of managing the numerous studies and coordinating the other public input processes during development and execution of the initial phase of the TMDL and program of implementation will involve significant effort. The role of a TMDL program coordination team has been identified to assist in this process.

Initially, this program coordination team will be helping the various stakeholders, the Regional Board and the Bay-Delta Authority to define their roles and responsibilities throughout the continuing development and eventual implementation of the initial TMDL phase. Next, a more detailed implementation plan, including a description and schedule of specific activities, will be developed based upon the recommendations of the Steering Committee and addressing the needs of the Regional Board. This detailed implementation plan will become the basis for the program of implementation included in the TMDL Basin Plan amendment.

During execution of the program of implementation, the TMDL program coordination team will provide facilitation of stakeholder meetings, website maintenance and other public outreach forums. The coordination team will also provide contract management support for the Bay-Delta Authority and technical oversight of the various technical studies. The contract for a consultant to provide this coordination is currently funded and underway using Proposition 13 bond money.

5.4 Other Considerations

5.4.1 Consideration of Alternative Mitigation Measures

To develop a practical and effective program of implementation, it may be important to evaluate alternate means of mitigating a contributing factor if direct control is found not practical or effective. As an example, the DWSC geometry is a factor that cannot be directly mitigated. Restoring the San Joaquin River to its historical depths would not be a practical means of mitigating its presence. As an alternate, aeration may be appropriate to restore all or part of the reduced loading capacity attributable to DWSC geometry. The initial phase of the program of implementation will include studies to consider a variety of aeration and non-aeration mitigation measures that may be used as alternatives to direct control of certain contributing factors.

In some cases, however, it may not be acceptable for certain sources or contributing factors to provide for mitigation, in whole or in part, by alternate means. If practical and effective direct controls of the source loads or contributing factor are available, mitigation by alternate means may not be an acceptable way of satisfying their respective TMDL requirements.

Further study may also find that some contributing factors may be mitigated by direct controls, but that it may take a number of years for the mitigation to get implemented and become effective. In such a case, the Regional Board may consider allowing mitigation by quicker alternate means (e.g. aeration) in the interim, while permanent direct controls become effective.

The program of implementation approach being developed provides the opportunity to consider the feasibility and effectiveness of both direct controls and alternate means of mitigating certain contributing factors. This approach follows the implementation framework recommended by the Steering Committee and should lead to the development of a practical and effective solution to the DO impairment.

5.4.2 Load-Trading Program

The Regional Board may also consider the development of an oxygen demand load-trading program. It may be useful for certain sources of oxygen demanding substances to have the flexibility to trade loads. This may be useful during certain seasons or critical low flow conditions when it may be more practical and effective for responsible entities to achieve the required source reduction of a source other than their own. Before the details of such a program can be considered, further study of oxygen demanding substance sources and their linkage mechanisms, as described in this program of implementation, is required.

5.4.3 Implementation Assurances and Progress

The initial phase of the TMDL provides the various responsible entities an opportunity to further develop and implement aeration and non-aeration mitigation alternatives as was suggested in the Steering Committee implementation framework. From this framework (as discussed in Section 5.3.4) a detailed description and schedule of activities is being developed for the program of implementation that will be included in the Basin Plan amendment. To the extent that different responsible entities make progress towards studying and implementing various mitigation measures, the apportioning of loading capacity and load allocations in the final TMDL can be

modified accordingly. The CVRWQCB and SWRCB can also consider what regulatory actions to take during the initial TMDL phase based on progress made by responsible entities.

One key point in the implementation plan being developed is the design and construction of the aeration demonstration facilities. Proposition 13 funds have been identified for the design and construction of these facilities. Restrictions on funds from this source, however, do not allow them to be used for long-term operation and maintenance of such a facility. Entities responsible for contributing factors that will be allowed to mitigate by means of aeration, will need to provide the resources for long-term operation and maintenance. Only contributing factors that cannot be practically or effectively controlled by direct measures will be considered for alternate mitigation by aeration. The Bay-Delta Authority, using Proposition 13 funds, has initiated the feasibility studies needed for the design of these facilities. Before the facilities are designed and constructed, however, written assurances must be provided by responsible entities that the facilities will be operated and maintained for a specified period of time. Various responsible entities provided letters of intent to the CVRWQCB in March 2003 describing their commitment to the process of developing an acceptable written assurance agreement to satisfy these and other implementation plan requirements.

Once an assurance package is negotiated and executed, continued compliance with the terms of the phased TMDL program of implementation would be assessed by performance of specific actions by responsible entities as outlined in the program of implementation schedule. Responsible entities would be in compliance with the TMDL if these actions were completed on schedule. If the responsible entities do not meet completion milestones in the TMDL program of implementation, then the CVRWQCB and/or SWRCB would take regulatory action, as needed, to require mitigation. The final TMDL will be modified accordingly.

5.4.4 USEPA Requirements for Phased TMDLs

Per USEPA guidance, a phased TMDL must identify implementation actions, a monitoring plan, and a schedule for considering revisions to the TMDL. The TMDL program of implementation described in this section provides a program of study that addresses these requirements.

CVRWQCB staff, together with the TMDL Program Coordinator and input from the watershed stakeholders, is preparing a detailed implementation plan. This plan will provide a description of specific implementation action and a schedule for their completion. The upstream studies provide extensive monitoring in the watershed to better identify sources and linkages. The aeration demonstration project will provide monitoring in the DWSC to better characterize the nature of the DO impairment and its controlling mechanisms. It will also provide for assessment of progress on mitigating the impairment as a result of the aeration project and other efforts.

Details of the implementation plan will be included along with this TMDL in the Basin Plan Amendment scheduled for consideration by the Regional Board in June 2004.

6.0 REFERENCES

Brown, R.T., Renahan, S.G. 2001. *Evaluation of San Joaquin River Flows at Stockton*. Jones & Stokes Report to the City of Stockton

California Department of Finance (CDF). 1999. California Department of Finance Web Page (<http://www.dof.ca.gov>).

California Department of Water Resources (DWR). 1994. *California Water Plan Update*. California Department of Water Resources Bulletin 160-94. Sacramento, CA.

Central Valley Regional Water Quality Control Board (CVRWQCB). 1967. *Water Quality Control Policy for the Sacramento - San Joaquin Delta*. Sacramento, CA.

Central Valley Regional Water Quality Control Board (CVRWQCB). 1975. *Water Quality Control Plan Report, Sacramento River Basin, Sacramento-San Joaquin Delta Basin, San Joaquin Basin*. Sacramento, CA.

Central Valley Regional Water Quality Control Board (CVRWQCB). 1994. *The Water Quality Control Plan for the Sacramento River Basin and the San Joaquin River Basin, Third Edition*. Sacramento, CA.

Central Valley Regional Water Quality Control Board (CVRWQCB). 1998. *The Water Quality Control Plan for the Sacramento River Basin and the San Joaquin River Basin, Fourth Edition*. Sacramento, CA.

Central Valley Regional Water Quality Control Board (CVRWQCB). 1999. *Regional Bay Protection & Toxic Cleanup Plan*. Sacramento, CA

Chen, C.W., Tsai, W. 2001. *Improvements and Calibrations of Lower San Joaquin River DO Model*. Report from Systech Engineering, Inc for CALFED 2000 Directed Action Grant.

Foe, C., Gowdy, M., McCarthy, M. 2002. *Strawman Source and Linkage Analysis for Low Dissolved Oxygen in the Stockton Deep Water Ship Channel*. Report from the California Regional Water Quality Control Board, Central Valley Region.

Hallock, R.R., Eldwell, Fry, D. 1970. *Migration of Adult King Salmon, *Oncorhynchus tshawytscha* in the San Joaquin Delta as Demonstrated by the Use of Sonic Tags*. California Department of Fish and Game Bulletin, 151.

Jones & Stokes Associates 1998. *Potential Solutions for Achieving the San Joaquin River Dissolved Oxygen Objectives*. Report to DeCuir & Somach and the City of Stockton.

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Kratzer, C.R., Shelton, J.L. 1998. *Water Quality Assessment of the San Joaquin-Tulare Basins, California: Analysis of available data on nutrients and suspended sediment in surface water, 1972-1990*. U.S. Geological Survey, Professional Paper 1587.

Lee, G.F., Jones-Lee, A. 2000. *Issues in Developing the San Joaquin River Deep Water Ship Channel DO TMDL*. G. Fred Lee & Associates Report to the San Joaquin River Dissolved Oxygen Total Maximum Daily Load Steering Committee and the California Regional Water Quality Control Board, Central Valley Region.

Lee, G.F., Jones-Lee, A. 2003. *Synthesis and Discussion of Findings on the Causes and Factors Influencing Low DO in the San Joaquin River Deep Water Ship Channel near Stockton, CA: Including 2002 Data*. G. Fred Lee & Associates Report to the San Joaquin River Dissolved Oxygen Total Maximum Daily Load Steering Committee and the CALFED Bay-Delta Program.

Nichol, G., Slinkard, S. 1999. *Jet Aeration of a Ship Channel*. Report from the U.S. Army Corps of Engineers, Sacramento District.

Oppenheimer, E.I., Grober, L.F. 2002. *Total Maximum Daily Load for Salinity and Boron in the Lower San Joaquin River*. Report from the California Regional Water Quality Control Board, Central Valley Region.

Ploss, L. 2003. *Implementation Plan, Dissolved Oxygen Total Maximum Daily Load, San Joaquin River Deep Water Ship Channel*. 4 February 2003 letter from San Joaquin River Dissolved Oxygen TMDL Steering Committee to Mr. Thomas Pinkos, Executive Director, California Regional Water Quality Control Board, Central Valley Region.

Ralston, C. 2001, *Personal Communication*. Department of Water Resources. Sacramento, CA.

San Joaquin Valley Drainage Program (SJVDP). 1990. *Fish and Wildlife Resources and Agricultural Drainage in the San Joaquin Valley, California. Vol. I and II*. Report from the San Joaquin Valley Drainage Program. Sacramento, CA.

State Water Resources Control Board (SWRCB). 1987. *SWRCB Order WQ 85-1 Technical Committee Report: Regulation of Agricultural Drainage to the San Joaquin River*. Sacramento, CA.

State Water Resources Control Board (SWRCB). 1991. *Water quality Control Plan for Salinity, San Francisco Bay/Sacramento-San Joaquin Delta Estuary*. (SWRCB Resolution No. 91-34). Sacramento, CA

State Water Resources Control Board (SWRCB). 1995. *Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary, Technical Appendix*. (SWRCB Resolution No. 95-24). Sacramento, CA

State Water Resources Control Board (SWRCB). 2000. *Water Right Decision 1641*(SWRCB Order WR 2000-02). Sacramento CA.

Stringfellow, W.T. 2001. *SJR TAC DO Calibration Field Trip to Rough and Ready Island*. Report to the DO TMDL Steering Committee, Technical Advisory Committee.

U.S. Army Corps of Engineers (USACOE) 1990. *Finding of No Significant Impact San Francisco Bay to Stockton Ship Channel: Dissolved Oxygen Mitigation Implementation*. Letter from Jack A. Le Cuyer, U.S. Army Corps of Engineers, Sacramento District dated 25 May 1990.

U.S. Environmental Protection Agency (USEPA) 1976. *Quality Criteria for Water*. EPA 440/9-76-023. Washington, D.C.

U.S. Environmental Protection Agency (USEPA) 1986. *Ambient Water Quality Criteria for Dissolved Oxygen* EPA 440/5-86-003. Washington D.C.

U.S. Geological Survey (USGS) 1997. *Water Resources Data – California, Water Year 1997, Volume 3, Southern Central Valley Basins and the Great Basin From Walker River to Truckee River*. Sacramento, CA.

Water and Power Resources Service and South Delta Water Agency, 1980. *Effects of the CVP Upon the Southern Delta Water Supply Sacramento-San Joaquin River Delta, California*. Stockton, CA.